



Special Situation Report

U.S. Army Corps of Engineers
Omaha District

Low Dissolved Oxygen Levels in Summer Powerplant Discharges from Fort Randall Dam, South Dakota



Aerial Photo of Fort Randall Dam Tailwaters

Report Number: CENWO-ED-HA/SSR/Fort Randall Tailwaters/2010

October 2010

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE OCT 2010		2. REPORT TYPE		3. DATES COVERED 00-00-2010 to 00-00-2010	
4. TITLE AND SUBTITLE Low Dissolved Oxygen Levels in Summer Powerplant Discharges from Fort Randall Dam, South Dakota				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U. S. Army Corps of Engineers, Omaha District ,1616 Capitol Avenue, Omaha, NE, 68102				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 76	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

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BACKGROUND INFORMATION

POTENTIAL FOR LOW DISSOLVED OXYGEN IN SUMMER DISCHARGES FROM FORT RANDALL DAM

In Lake Francis Case, water is routed to the dam intake structure through a submerged approach channel that connects to the old Missouri River channel (Figure 1). The invert elevation (i.e., 1229 ft-msl) of the intake for the power tunnels at Fort Randall Dam is 2 feet above the bottom of the approach channel. Thermal stratification that develops in Lake Francis Case during the summer results in a significant water density gradient between the epilimnion and hypolimnion. Due to the water density gradient, restricted approach channel, and bottom withdrawal, the vertical extent that water is withdrawn from Lake Francis Case in the summer is dependent upon the discharge rate of the dam. During periods of lower flows through the powerplant water is pulled from lower elevations along the bottom of the reservoir. Higher powerplant flows are believed to create enough “turbulence” near the dam intake structure to allow warmer, less dense water to be drawn from higher elevations in Lake Francis Case.

Degradation of dissolved oxygen occurs in the quiescent hypolimnion of Lake Francis Case during summer thermal stratification. Dissolved oxygen degradation is greatest near the reservoir bottom and expands upward in the water column as summer thermal stratification continues. Past water quality monitoring indicates that the lower depths of Lake Francis Case typically degrade to hypoxic conditions by early July. At that time, a heightened potential exists for hypoxic water to be drawn into the powerplant and discharged downstream to the Missouri River. The discharge of hypoxic water could result in dissolved oxygen conditions in the Fort Randall tailwaters not meeting South Dakota’s water quality standards minimum criteria for dissolved oxygen.

PAST WATER QUALITY MONITORING AT THE FORT RANDALL POWERPLANT

A water quality monitoring station is located in the Fort Randall powerplant (Figure 1). Water is withdrawn from the “raw water” supply line and routed through a flow chamber where a water quality monitor is located that logs hourly water temperature and dissolved oxygen levels. The monitored “raw water” is believed to represent water quality conditions in Lake Francis Case at the dam intake structure and in the water discharged to the Missouri River tailwaters. During the 6-year period 2004 through 2007 and 2009, 2,982 hourly measurements of dissolved oxygen were recorded in the powerplant in August (no measurements were recorded in 2008 due to monitoring equipment failure). Of these measurements, 546 (18%) were less than South Dakota’s 5 mg/l minimum dissolved oxygen water quality standards’ criterion for the protection of Warmwater Permanent Fish Life Propagation. The lowest dissolved oxygen measurements were associated with low- or no-flow discharge conditions. The no-flow conditions may be measurements of “static water” in the penstocks that is not being continuously discharged. This water is believed to have been drawn into the penstocks along the reservoir bottom as power generation was ramped down. The lowest dissolved oxygen concentration recorded was 2.0 mg/l on August 25 and 26, 2007. The low dissolved oxygen levels are attributed to hypoxic conditions in the hypolimnion of Lake Francis Case and the bottom withdrawal of water from the reservoir. A potential concern is whether the low dissolved oxygen levels monitored in the powerplant are reflective of dissolved oxygen levels occurring in the Missouri River tailwaters immediately downstream of the Fort Randall Dam.

EXISTING WATER QUALITY CONDITIONS

FORT RANDALL POWERPLANT

Water quality conditions monitored at the Fort Randall powerplant in 2010 were reviewed. Figures 2 and 3 show hourly water temperature and dissolved oxygen levels monitored from June 1 through September 30, 2010. Figure 4 shows hourly dissolved oxygen and powerplant discharge for the period July 1 through August 30, 2010. As seen in Figures 2 - 4, the monitored water temperature and dissolved oxygen were more dependent on dam discharge in June and July. Dissolved oxygen levels continually decreased during June, and first went below South Dakota's 5 mg/l dissolved oxygen water quality standard minimum criterion on July 8. The lowest dissolved oxygen occurrences tend to be associated with lower dam discharges.

LAKE FRANCIS CASE

Pool Levels

To maximize the service to all of the authorized purposes, given the physical and authorization limitations of the Missouri River Mainstem System, the total storage available in the Mainstem System is divided into four regulation zones that are applied to the individual reservoirs. These four regulation zones are: 1) Exclusive Flood Control Zone (EFCZ), 2) Annual Flood Control and Multiple Use Zone (AFCMUZ), 3) Carryover Multiple Use Zone (CMUZ), and 4) Permanent Pool Zone (PPZ). The currently defined elevations for the four regulation zones at Lake Francis Case are: 1375-1365 ft-msl (EFCZ), 1365-1350 ft-msl (AFCMUZ), 1350-1320 ft-msl (CMUZ), and 1320-1227 ft-msl (PPZ).

Figure 5 plots the midnight pool elevations for Lake Francis Case from 1-June-2010 through 1-October-2010. Pool levels in Lake Francis Case peaked in late-June (Figure 5). Higher pool levels in Lake Francis Case enforce summer thermal stratification of the reservoir and an increased hypolimnetic volume. Decreasing pool levels will enhance mixing of the reservoir. Mixing of the reservoir will lead to the breakdown of thermal stratification and eventual "re-aeration" of the lower depths of the reservoir.

Water Quality

Ambient Monitoring

Four ambient water quality monitoring sites are located along the length of Lake Francis Case at RM880, RM911, RM940, and RM968 (Figure 6). The sites are located at deepwater locations over the old submerged Missouri River channel. The sites are monitored monthly from May through September, and depth-profiles (1-meter increments) are measured for several parameters including water temperature and dissolved oxygen.

17-June-2010

Water quality monitoring of the ambient monitoring sites on Lake Francis Case occurred on June 17, 2010. Longitudinal contour plots of water temperature and dissolved oxygen were constructed from depth-profile data collected at RM880, RM911, RM940, and RM968. Figures 7 and 8, respectively, show the longitudinal contour plots for water temperature and dissolved oxygen. On June 17, Lake Francis Case was thermally stratified and a distinct hypolimnion had

formed. The thermocline was located at about elevation 1300 ft-msl at a depth of about 20 meters (Figure 7).

15-July-2010 Monitoring

Water quality monitoring of the ambient monitoring sites on Lake Francis Case occurred on July 15, 2010. Longitudinal contour plots of water temperature and dissolved oxygen were constructed from depth-profile data collected at RM880, RM911, RM940, and RM968. Figures 9 and 10, respectively, show the longitudinal contour plots for water temperature and dissolved oxygen. On July 15, Lake Francis Case was thermally stratified and the thermocline was located at about elevation 1285 ft-msl at a depth of about 25 meters (Figure 9).

12-August-2010 Monitoring

Water quality monitoring of the ambient monitoring sites on Lake Francis Case occurred on August 12, 2010. Longitudinal contour plots of water temperature and dissolved oxygen were constructed from depth-profile data collected at RM880, RM911, RM940, and RM968 on August 12. Figures 11 and 12, respectively, show the longitudinal contour plots for water temperature and dissolved oxygen. On August 12, Lake Francis Case remained thermally stratified and the thermocline was located at about elevation 1260 ft-msl at a depth of about 30 meters (Figure 11).

16-September-2010 Monitoring

Water quality monitoring of the ambient monitoring sites on Lake Francis Case occurred on September 16, 2010. Longitudinal contour plots of water temperature and dissolved oxygen were constructed from depth-profile data collected at RM880, RM911, and RM968 on September 16. Monitoring at RM940 was not conducted because of an unusable boat ramp due to siltation and low water conditions. Figures 13 and 14, respectively, show the longitudinal contour plots for water temperature and dissolved oxygen. On September 16, Lake Francis Case was no longer thermally stratified (Figure 13).

Investigative Monitoring

Additional water quality monitoring was conducted on August 19, 2010 to evaluate the variation in thermal stratification and dissolved oxygen levels in Lake Francis Case along Fort Randall Dam. Four sites were monitored in the deepwater region of the reservoir along the dam and submerged approach channel to the intake structure (Figure 15). At each for the four sites a depth-profile, in 1-meter increments, was measured for water temperature and dissolved oxygen. This information was used to construct a contour plot for water temperature and dissolved oxygen along the line through each of the four sites from site FTRLK0880A to site FTRLK0880D (Figures 16 and 17).

FORT RANDALL DAM TAILWATERS

Ambient Monitoring

An ambient monitoring site (i.e., FTRRRTW1B) is located on the Fort Randall Dam tailwaters approximately 1-mile downstream of the dam on the east bank in the area of the boat ramp (Figure 1). A monthly grab sample is collected from the bank at this site year-round.

On July 15, August 12, and September 16, 2010, water quality samples were collected at the Fort Randall powerplant (FTRPP1) and the Fort Randall Dam tailwaters (FTRRRTW1B). The water temperature and dissolved oxygen levels monitored in the powerplant and tailwaters on these dates are given in Table 1. It would seem that dissolved oxygen levels below 5.0 mg/l in the powerplant discharge could result in levels below South Dakota's 5 mg/l minimum dissolved oxygen water quality standard criterion in the Fort Randall Dam tailwaters.

Table 1.
Results of Paired Monitoring Conducted at Sites FTRPP1 and FTRRRTW1B during July through September 2010.

Date	Site	Time	Water Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (% Saturation)
15-Jul-2010	FTRPP1	12:10	22.6	5.9	71.2
15-Jul-2010	FTRRRTW1B	12:50	21.8	6.0	70.6
12-Aug-2010	FTRPP1	14:00	25.7	5.4	68.1
12-Aug-2010	FTRRRTW1B	14:30	25.7	5.2	66.4
16-Sep-2010	FTRPP1	16:30	22.2	8.3	100.3
16-Sep-2010	FTRRRTW1B	17:00	22.3	9.2	109.9
Flow Conditions: 15-Jul-2010 12:00: Powerplant Flow = 37,739 cfs, Spillway Flow = 0 12-Aug-2010 14:00: Powerplant Flow = 39,542 cfs, Spillway Flow = 0 16-Sep-2010 17:00: Powerplant Flow = 39,918 cfs, Spillway Flow = 6,181 cfs					

Investigative Monitoring

Additional water quality monitoring of the Fort Randall tailwaters was initiated in July 2010 to assess the potential occurrence of dissolved oxygen conditions below the South Dakota dissolved oxygen water quality standards criterion of 5 mg/l. A Sampling and Analysis Plan (SAP) was developed to monitor dissolved oxygen and water temperature conditions in the Fort Randall powerplant inflow and at representative locations in the Fort Randall Dam tailwaters.

The locations monitored in the Fort Randall Dam tailwaters as part of the investigative monitoring are shown in Figure 18. Because of flows through the tailwaters, water temperature and dissolved oxygen measurements were collected while drifting through the sampling site. The yellow lines in Figure 18 show the targeted drift paths for the identified sampling sites. Depth-profiles, in 1-meter increments, were collected for water temperature and dissolved oxygen.

27-July-2010 Monitoring

Investigative monitoring of the Fort Randall Dam tailwaters was initiated on 27-July-2010. Table 2 provides the results of the Fort Randall Dam tailwaters monitoring that was conducted on 27-July-2010.

Table 2.
Results of 27-July-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	21.9	4.1	47.6	22.5	4.5	53.5	23.1	5.1	61.2
1	21.9	4.0	46.6	22.5	4.4	52.6	23.1	5.1	61.2
2	22.0	3.9	46.2	22.5	4.4	52.3	23.2	5.1	61.1
3	22.0	3.9	45.0	22.5	4.4	51.9	23.1	5.0	60.4
4	22.0	4.1	47.7	22.5	4.4	51.9	23.3	5.0	60.5
5	22.0	4.0	46.7	22.5	4.4	52.0	23.3	5.1	61.5
6	22.1	4.0	46.8	22.5	4.3	51.7	23.3	5.1	61.4

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	21.9	4.6	54.2	22.4	4.9	57.2	22.7	4.7	56.3
1	21.9	4.2	48.1	22.4	4.5	53.3	22.8	4.8	56.9
2	21.9	4.0	47.2	22.3	4.3	50.9	22.7	4.7	56.2
3	21.9	4.0	46.8	22.3	4.2	49.8	22.8	4.7	56.4
4	21.9	4.0	46.5	22.3	4.2	49.6	22.8	4.7	56.7
5	21.9	3.9	46.5	22.3	4.2	49.7	22.9	4.7	56.9

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	21.9	5.1	59.7	22.3	5.1	60.5	22.8	4.8	57.0
1	21.9	4.6	53.5	22.3	4.7	55.3	22.8	4.8	57.0
2	22.0	4.1	48.6	22.3	4.4	51.5	22.8	4.8	56.5
3	22.0	4.1	47.8						

Times at Start of Measurements:

Near-Dam: 6:10

Spillway Confluence: 6:30

Downstream: 6:45

Lake Francis Case Pool Elevation: 1365.5 ft-msl

Fort Randall Dam Tailwater Elevation: 1232.5 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
7/27/10 6:00	23.5	4.9	60.4

Powerplant Discharge: 26,621 cfs

Spillway Discharge: 0 cfs

Figures 19, 20, and 21, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 27-July-2010. Figure 22 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

3-August-2010 Monitoring

Table 3 provides results of monitoring conducted at Fort Randall Dam tailwaters on 3-August-2010. Monitoring was influenced (i.e., location of drift paths) by extreme fog conditions (<50-foot visibility).

Table 2.
Results of 3-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	23.3	5.0	61.1	23.7	5.3	65.0	24.7	6.5	61.1
1	23.2	4.7	57.1	23.7	4.9	60.5	24.6	6.0	57.1
2	23.2	4.4	53.5	23.7	4.8	59.4	24.7	5.9	53.5
3	23.2	4.3	52.8	23.7	4.8	58.7	24.7	5.9	52.8
4	23.2	4.3	52.4	23.6	4.8	58.3	24.8	6.0	52.4
5	23.2	4.3	52.2	23.6	4.6	57.3	24.8	6.1	52.2
6	23.3	4.3	52.1	23.6	4.5	56.5	24.8	6.1	52.1

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	23.2	4.3	53.1	23.6	5.5	67.4	24.9	6.5	82.1
1	23.2	4.3	52.9	23.7	4.9	60.8	24.8	6.1	77.0
2	23.2	4.3	52.5	23.7	4.8	59.5	24.7	6.1	76.2
3	23.2	4.2	52.2	23.7	4.8	59.1	24.7	6.0	75.4
4				23.7	4.8	58.8	24.7	6.0	75.3
5							24.6	6.0	75.1

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	23.3	5.0	61.8	23.6	5.4	66.0	24.5	6.3	79.4
1	23.3	4.6	56.7	23.6	5.0	62.1	24.5	6.0	75.1
2	23.3	4.5	54.7	23.5	4.8	59.0	24.5	5.8	73.0
3	23.3	4.4	53.9	23.5	4.6	57.1	24.5	5.8	72.8

Times at Start of Measurements:

Near-Dam: 5:40

Spillway Confluence: 5:55

Downstream: 6:05

Lake Francis Case Pool Elevation: 1362.5 ft-msl

Fort Randall Dam Tailwater Elevation: 1233.6 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/3/10 7:00	24.3	5.0	62.5

Powerplant Discharge: 34,800 cfs

Spillway Discharge: 0 cfs

Figures 23, 24, and 25, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 3-August-2010. Figure 26 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

5-August-2010 Monitoring

Table 4 provides results of monitoring conducted at Fort Randall Dam tailwaters on 5-August-2010.

Table 4.
Results of 5-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	24.0	5.4	65.4	24.3	5.8	69.0	25.1	6.4	81.0
1	24.1	5.0	61.8	24.4	5.4	66.6	25.0	6.3	79.3
2	24.0	5.0	61.5	24.3	5.3	66.1	25.0	6.2	70.3
3	24.1	5.0	61.5	24.4	5.3	65.8	24.7	6.0	74.3
4	24.1	5.0	61.5	24.3	5.2	65.1	24.5	5.5	68.6
5	24.1	4.9	61.0	24.3	5.2	64.9	24.6	5.5	69.7
6	24.1	4.9	61.0	24.3	5.2	64.6	24.6	5.5	69.3

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	24.0	4.9	60.7	24.3	5.2	65.2	24.9	6.1	76.8
1	24.0	4.9	60.6	24.4	5.3	65.8	25.0	6.1	77.5
2	24.0	4.9	60.5	24.3	5.2	65.0	25.0	6.1	77.5
3	24.0	4.9	60.4	24.3	5.2	64.3	24.9	6.1	77.0
4	24.0	4.9	60.4	24.3	5.2	64.3	25.0	6.1	77.1
5	24.0	4.9	60.0	24.2	5.1	63.9	24.9	6.0	75.8

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	24.0	4.9	61.1	24.4	5.5	68.2	24.8	6.0	76.0
1	24.0	4.9	61.0	24.4	5.5	68.1	24.8	6.0	76.1
2	24.0	4.9	60.8	24.4	5.4	67.9	24.8	6.0	75.9
3	24.0	4.9	60.7						

Times at Start of Measurements:

Near-Dam: 6:00

Spillway Confluence: 6:15

Downstream: 6:30

Lake Francis Case Pool Elevation: 1362.1 ft-msl

Fort Randall Dam Tailwater Elevation: 1233.6 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/5/10 7:00	25.1	6.3	79.8

Powerplant Discharge: 33,050 cfs

Spillway Discharge: 0 cfs

Figures 27, 28, and 29, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 5-August-2010. Figure 30 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

10-August-2010 Monitoring

Table 5 provides results of monitoring conducted at Fort Randall Dam tailwaters on 10-August-2010.

Table 5.
Results of 10-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	24.1	4.5	55.5	24.5	4.8	60.5	25.3	6.1	77.8
1	24.3	4.5	55.9	24.5	4.8	60.2	25.4	6.1	78.1
2	24.3	4.5	55.9	24.5	4.8	60.0	25.4	6.1	77.6
3	24.2	4.4	54.7	24.5	4.8	59.8	25.4	6.1	77.7
4	24.2	4.4	54.3	24.5	4.8	59.9	25.7	6.4	83.5
5	24.2	4.4	54.3	24.5	4.8	60.0	25.6	6.5	82.6
6	24.2	4.3	53.8	24.5	4.8	60.0	25.7	6.5	83.7

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	24.2	4.5	55.6	24.7	5.1	63.8	25.9	7.0	89.6
1	24.2	4.4	54.8	24.5	5.0	61.4	25.9	6.9	89.1
2	24.2	4.4	54.3	24.5	4.8	60.7	25.9	6.9	88.3
3	24.2	4.3	54.1	24.5	4.8	60.9	25.8	6.8	87.0
4	24.2	4.3	53.9	24.6	4.9	61.2	25.8	6.8	87.4
5	24.2	4.3	53.7	24.6	4.9	61.5	25.8	6.8	87.2

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	24.2	4.5	56.0	24.8	5.3	67.3	25.7	6.7	85.8
1	24.2	4.5	55.9	24.8	5.3	67.0	25.7	6.7	86.0
2	24.2	4.5	55.8	24.8	5.3	66.4	25.7	6.7	85.3
3	24.3	4.5	56.1						

Times at Start of Measurements:

Near-Dam: 8:20

Spillway Confluence: 8:35

Downstream: 8:50

Lake Francis Case Pool Elevation: 1360.9 ft-msl

Fort Randall Dam Tailwater Elevation: 1234.5 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/10/10 9:20	25.3	5.4	68.3

Powerplant Discharge: 39,459 cfs

Spillway Discharge: 0 cfs

Figures 31, 32, and 33, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 10-August-2010. Figure 34 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

12-August-2010 Monitoring

Table 6 provides results of monitoring conducted at Fort Randall Dam tailwaters on 12-August-2010.

Table 6.
Results of 12-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	24.4	4.1	51.7	24.8	4.5	57.0	25.4	5.3	68.1
1	24.5	4.1	52.0	24.8	4.5	56.6	25.4	5.2	67.0
2	24.5	4.1	51.8	24.8	4.4	56.1	25.4	5.2	66.9
3	24.5	4.1	51.7	24.8	4.4	55.8	24.3	5.2	66.2
4	24.5	4.1	51.9	24.7	4.3	55.1	25.3	5.2	66.1
5	24.5	4.1	51.9	24.7	4.3	54.9	25.3	5.1	66.0
6	24.5	4.1	51.8	24.7	4.3	54.9	25.4	5.2	66.9

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	24.4	4.1	51.6	24.9	4.7	59.5	25.9	5.9	76.7
1	24.4	4.1	51.5	24.9	4.7	59.3	25.9	5.9	76.7
2	24.4	4.1	51.1	25.0	4.7	59.6	25.7	5.8	74.9
3	24.4	4.1	51.1	24.9	4.7	59.9	25.8	5.8	74.8
4	24.4	4.0	50.8	24.9	4.6	58.9	25.8	5.8	75.3
5				24.9	4.6	58.3	25.9	5.9	76.2

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	24.5	4.2	52.7	24.9	4.6	58.8	25.7	5.7	73.4
1	24.5	4.2	52.6	24.9	4.6	58.3	25.7	5.7	73.0
2	24.5	4.2	52.4	24.9	4.6	58.5	25.6	5.6	72.6
3	24.5	4.1	52.3				25.6	5.6	72.1

Times at Start of Measurements:

Near-Dam: 8:30

Spillway Confluence: 8:45

Downstream: 9:00

Lake Francis Case Pool Elevation: 1360.8 ft-msl

Fort Randall Dam Tailwater Elevation: 1234.2 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/12/10 8:20	25.5	5.2	66.3

Powerplant Discharge: 39,500 cfs

Spillway Discharge: 0 cfs

Figures 35, 36, and 37, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 12-August-2010. Figure 38 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

17-August-2010 Monitoring

Table 7 provides results of monitoring conducted at Fort Randall Dam tailwaters on 17-August-2010.

Table 7.
Results of 17-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	25.2	4.8	60.0	25.6	5.5	69.9	26.1	6.5	83.2
1	25.2	4.7	60.0	25.5	5.4	67.8	26.1	6.4	81.9
2	25.2	4.8	60.1	25.5	5.3	67.1	26.1	6.4	81.9
3	25.2	4.7	59.4	25.4	5.2	66.1	26.0	6.3	81.0
4	25.2	4.7	59.9	25.4	5.1	65.3	26.1	6.3	80.9
5	25.2	4.7	59.7	25.4	5.1	65.2	26.1	6.3	81.4
6	25.2	4.8	60.4	25.5	5.2	66.0	26.1	6.3	81.0

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	25.1	4.7	59.0	25.7	5.7	73.2	26.3	6.6	85.5
1	25.1	4.7	58.9	25.7	5.7	72.9	26.3	6.6	85.5
2	25.1	4.7	58.8	25.7	5.7	73.2	26.3	6.6	85.2
3	25.1	4.7	58.7	25.7	5.7	72.0	26.3	6.6	85.3
4				25.6	5.6	71.5	26.3	6.6	85.4
5				25.6	5.6	71.0	26.3	6.6	85.2

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	25.2	4.8	60.4	25.7	5.9	74.7	26.2	6.5	83.9
1	25.2	4.8	60.2	25.7	5.8	74.4	26.2	6.5	84.0
2	25.2	4.8	60.2	25.7	5.8	74.4	26.2	6.5	83.8
3	25.2	4.8	60.6						

Times at Start of Measurements:

Near-Dam: 9:15

Spillway Confluence: 9:20

Downstream: 9:30

Lake Francis Case Pool Elevation: 1359.2 ft-msl

Fort Randall Dam Tailwater Elevation: 1234.5 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/17/10 8:50	26.0	6.0	78.8

Powerplant Discharge: 40,400 cfs

Spillway Discharge: 0 cfs

Figures 39, 40, and 41, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 17-August-2010. Figure 42 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

19-August-2010 Monitoring

Table 8 provides results of monitoring conducted at Fort Randall Dam tailwaters on 19-August-2010.

Table 8.
Results of 19-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	25.0	4.8	60.6	25.3	5.7	82.9	26.1	6.8	88.0
1	25.0	4.8	60.4	25.4	5.5	69.8	26.1	6.9	89.1
2	25.0	4.8	61.2	25.4	5.6	70.8	26.1	6.8	88.2
3	25.0	4.8	60.5	25.4	5.6	71.3	26.0	6.8	87.7
4	25.0	4.8	60.2	25.4	5.6	71.1	26.1	6.8	87.2
5	24.9	4.7	59.5	25.4	5.6	70.9	26.1	6.8	87.3
6	25.0	4.7	59.4	25.3	5.5	69.9	26.0	6.7	86.7

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	25.0	4.8	61.2	25.3	5.3	67.5	26.1	6.8	87.5
1	25.0	4.8	61.0	25.3	5.3	67.9	26.1	6.8	87.5
2	25.0	4.8	60.3	25.3	5.3	67.7	26.1	6.7	87.1
3	25.0	4.8	60.1	25.3	5.4	68.2	26.1	6.7	87.0
4	25.0	4.7	60.0	25.3	5.4	68.5	26.1	6.7	86.1
5	25.0	4.7	59.9	25.3	5.4	68.3			

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	25.1	5.0	62.8	25.4	5.6	71.3	25.8	6.4	82.6
1	25.1	5.0	63.0	25.4	5.6	71.2	25.8	6.4	81.7
2	25.1	5.0	62.8	25.4	5.6	71.2	25.8	6.3	81.2
3	25.1	4.9	62.3	25.4	5.6	71.1	25.8	6.3	81.0

Times at Start of Measurements:

Near-Dam: 18:00

Spillway Confluence: 18:15

Downstream: 18:30

Lake Francis Case Pool Elevation: 1358.6 ft-msl

Fort Randall Dam Tailwater Elevation: 1234.9 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/19/10 17:30	25.9	5.8	75.1

Powerplant Discharge: 40,449 cfs

Spillway Discharge: 0 cfs

Figures 43, 44, and 45, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 19-August-2010. Figure 46 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

24-August-2010 Monitoring

Table 9 provides results of monitoring conducted at Fort Randall Dam tailwaters on 24-August-2010.

Table 9.
Results of 24-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	25.3	4.7	59.2	25.4	5.2	65.4	25.6	5.8	73.0
1	25.2	4.7	58.9	25.4	5.2	65.0	25.6	5.8	73.0
2	25.3	4.7	58.8	25.4	5.2	65.0	25.6	5.6	70.9
3	25.3	4.7	58.7	25.4	5.1	64.4	25.5	5.5	68.7
4	25.3	4.7	58.6	25.4	5.1	64.3	25.5	5.4	68.2
5	25.2	4.7	58.5	25.4	5.1	64.0	25.5	5.4	68.8
6	25.2	4.6	58.5	25.4	5.1	64.0	25.6	5.5	69.0

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	25.2	4.7	58.9	25.4	5.2	65.1	25.6	5.8	73.2
1	25.2	4.7	58.8	25.4	5.2	65.2	25.6	5.8	73.2
2	25.2	4.7	58.7	25.4	5.2	65.1	25.6	5.8	73.0
3	25.2	4.7	58.4	25.4	5.2	65.1	25.6	5.8	72.9
4	25.2	4.6	58.4	25.4	5.1	64.7			
5				25.4	5.1	64.6			

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	25.4	6.6	83.5	25.4	5.2	65.5	25.5	5.8	72.9
1	25.5	6.6	83.9	25.4	5.2	65.3	25.5	5.7	72.7
2	25.5	6.6	83.9	25.4	5.1	64.9	25.6	5.7	72.5
3	25.5	6.7	84.1						

Times at Start of Measurements:

Near-Dam: 9:20

Spillway Confluence: 9:30

Downstream: 9:40

Lake Francis Case Pool Elevation: 1358.0 ft-msl

Fort Randall Dam Tailwater Elevation: 1235.2 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/24/10 9:50	25.7	6.3	81.9

Powerplant Discharge: 41,055 cfs

Spillway Discharge: 6,334 cfs

Figures 47, 48, and 49, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 24-August-2010. Figure 50 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

26-August-2010 Monitoring

Table 10 provides results of monitoring conducted at Fort Randall Dam tailwaters on 26-August-2010.

Table 10.
Results of 26-August-2010 Monitoring at Fort Randall Dam Tailwaters

Depth (M)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
NEAR-DAM	FTRTW3E (East)			FTRTW3M (Middle)			FTRTW3W (West)		
0.1	25.1	5.6	70.1	25.2	6.2	78.7	25.4	7.0	88.5
1	25.1	5.6	70.1	25.2	6.2	78.3	25.4	7.0	88.4
2	25.1	5.5	69.8	25.2	6.2	78.0	25.4	7.0	88.6
3	25.1	5.5	69.9	25.2	6.1	77.5	25.4	7.0	88.8
4	25.1	5.5	69.8	25.2	6.1	77.5	25.4	7.0	88.6
5	25.1	5.5	69.6	25.2	6.1	77.5	25.4	7.0	88.5
6	25.1	5.5	69.3	25.2	6.1	77.4	25.4	6.9	87.8

SPILLWAY CONFLUENCE	FTRTW2E (East)			FTRTW2M (Middle)			FTRTW2W (West)		
0.1	25.0	5.7	71.8	25.2	6.3	80.5	25.4	7.0	90.0
1	25.0	5.7	71.7	25.2	6.4	81.6	25.4	7.1	89.8
2	25.0	5.7	71.5	25.2	6.4	81.0	25.4	7.1	89.9
3	25.0	5.7	71.4	25.2	6.4	80.6			
4				25.2	6.3	80.4			
5				25.2	6.3	80.2			

DOWNSTREAM	FTRTW1E (East)			FTRTW1M (Middle)			FTRTW1W (West)		
0.1	25.2	7.0	88.9	25.2	6.3	79.6	25.3	7.1	89.6
1	25.2	7.0	88.1	25.2	6.3	79.4	25.3	7.0	89.4
2	25.2	6.9	88.2	25.2	6.2	79.1	25.3	7.0	89.1
3	25.2	6.9	86.1				25.3	7.0	88.9

Times at Start of Measurements:

Near-Dam: 9:45

Spillway Confluence: 10:00

Downstream: 10:10

Lake Francis Case Pool Elevation: 1357.6 ft-msl

Fort Randall Dam Tailwater Elevation: 1235.5 ft-msl

Powerplant "Raw Water: Supply Line Measurements:

Date/Time	Temp. (°C)	D.O. (mg/l)	D.O. (%Sat)
8/26/10 10:30	25.5	6.4	82.7

Powerplant Discharge: 39,800 cfs

Spillway Discharge: 6,200 cfs

Figures 51, 52, and 53, respectively, display transect contour plots that were constructed to depict the dissolved oxygen concentrations measured across the Fort Randall Dam tailwaters at the near-dam (FTRTW3), spillway confluence (FTRTW2), and downstream (FTRTW1) sites on 26-August-2010. Figure 54 displays an aerial contour plot of the water-column average dissolved oxygen concentrations in the tailwaters based on the 1-meter incremental depth-profile measurements.

DISCUSSION

THERMAL STRATIFICATION AND DISSOLVED OXYGEN LEVELS IN LAKE FRANCIS CASE

Longitudinal Stratification

Thermal Conditions

Monitoring of Lake Francis Case on June 17, July 15, and August 12, indicated significant thermal stratification of the reservoir (Figures 7, 9, and 11). Monitoring on September 16 indicated that “fall turnover” had occurred and thermal stratification of the reservoir had broken down (Figure 13). The differences in surface and bottom water temperatures measured on June 17, July 15, and August 12, were, respectively, 9° C, 9° C, and 5° C. The depth of the thermocline on June 17, July 15, and August 12, was, respectively, 20, 25, and 30 meters.

Dissolved Oxygen Conditions

During the summer of 2010, dissolved oxygen conditions in Lake Francis Case varied longitudinally from the dam to the reservoir’s upstream reaches and vertically from the reservoir surface to the bottom. An area of low dissolved oxygen (i.e., <5 mg/l) was first monitored in July and occurred along the reservoir bottom from the dam upstream to RM925 (Figure 10). A similar area of low dissolved oxygen was again monitored in August, with the most hypoxic water located along the reservoir bottom near the dam (Figure 12). The area of low dissolved oxygen had dissipated when monitored in mid-September, ostensibly with the occurrence of “fall turnover.” The lowest dissolved oxygen concentration measured near the reservoir bottom on June 17, July 15, and August 12, were, respectively, 5.5, 1.6, and 0.4 mg/l.

Latitudinal Stratification at Fort Randall Dam

Figures 16 and 17 depict the thermal stratification and dissolved oxygen conditions that were monitored along Fort Randall Dam on August 19, 2010. The depicted area runs from the deepwater area of the submerged Missouri River channel (i.e., west side of the reservoir) to the east through the approach channel to the dam intake structure. Significant thermal stratification and hypoxic conditions occurred through this area (Figures 16 and 17). In the approach channel, warmer water with higher dissolved oxygen levels is seemingly drawn down from higher elevations in the area nearer the intake structure. This is attributed to “turbulence” created near the intake structure by the bottom withdrawal of water from the reservoir during higher inflows to the powerplant. The turbulence ostensibly allows warmer, less dense water higher in dissolved oxygen to be drawn down towards the reservoir bottom at the intake structure.

DISSOLVED OXYGEN LEVELS MONITORED IN THE FORT RANDALL DAM TAILWATERS

Water quality monitoring of the Fort Randall Dam tailwaters over the period 27-July-2010 through 26-August-2010 indicates that dissolved oxygen levels generally improved from the first time they were monitored on July 27. On July 27, dissolved oxygen levels throughout the tailwaters were below South Dakota’s dissolved oxygen water quality standard of 5 mg/l (Figures 19, 20, 21, and 22). Subsequent tailwaters monitoring on August 3, 5, 10, 12, 17, and 19 generally indicated dissolved oxygen levels above the 5 mg/l water quality standard along the west bank, and below the 5 mg/l standard along the east bank when no water was being spilled (Figures 23 - 46). The spillway enters the tailwater area about 1,000 meters downstream

of the dam, and the downstream monitored transect was located downstream of the spillway inflow (Figure 18). Monitoring on August 24 and 26 indicated that spilling water re-oxygenated the Fort Randall tailwaters along the east bank downstream of the spillway inflow (Figures 47 - 54). Also, higher dam discharges generally resulted in higher dissolved oxygen levels in the tailwaters – especially earlier in the monitored period.

The dissolved oxygen levels monitored in the Fort Randall tailwaters indicate that dissolved oxygen levels are higher along the west bank than along the east bank (Figures 19 - 54). The difference between the dissolved oxygen levels monitored along the east and west banks is up to 2 mg/l. The following is provided as a possible explanation for the differences in dissolved oxygen levels along the east and west banks:

The following correspondence occurred last year regarding the Fort Randall approach channel to the dam intake structure: *“Based on a Dive inspection performed a few years ago issues are more likely related to sloughing of the bank by Unit #1. The concrete slab out front was mostly clear with the exception of near Units 1 and 2. Silt built up was such at Unit 1 that the sloughed bank material was only cleared enough to put the trash rack back in place.”*

Units 1 and 2 are on the west end of the dam intake structure.

The Dive inspection indicates that there is some blockage on the west end of the intake channel that may be restricting flows into Units 1 and 2. To further investigate this situation, depth soundings (i.e., electronic depth indicator) were taken along the front of the intake structure. These soundings indicated the following depths in front of Units 1 through 5: Unit 1) 29.8 meters, Unit 2) 35.5 meters, Unit 3) 38 meters, Unit 4) 38 meters, and Unit 5) 38 meters. Sloughing has apparently occurred and deposited material in front of Units 1 and 2. The deposited material seemingly has created a barrier in front of Units 1 and 2 that is acting like a submerged weir and allowing Units 1 and 2 to pull water from higher elevations in the reservoir than the other Units. Water from higher elevations will be warmer and have higher dissolved oxygen levels. Fort Randall Project staff have indicated that “swirling” water is occasionally visible at the surface of Lake Francis Case in the area of Unit 1 during higher dam discharges. Units 1 and 2 are seemingly passing water with higher dissolved oxygen along the west bank of the tailwaters.

A review of the monitoring results seemingly indicate that the dissolved oxygen levels measured at the powerplant monitoring site (i.e., raw water supply) are about 1 mg/l higher than those measured along the east bank? If, as reasoned above, dissolved oxygen levels in Units 1 and 2 are higher than the other Units, the dissolved oxygen level measured in the powerplant raw water supply line would be influenced by the input of water from the various Units to the raw water supply line. Another factor would be where water is drawn off the raw water supply line for measurement in relation to inputs to the raw water line from the Units.

ARE EXCEEDENCES OF THE STATE WATER QUALITY STANDARD FOR DISSOLVED OXYGEN IMPAIRING THE DESIGNATED WARMWATER PERMANENT FISH LIFE PROPAGATION BENEFICIAL USE IN THE FORT RANDALL DAM TAILWATERS AREA?

South Dakota’s 303(d) impaired waters assessment methodologies for streams regarding conventional parameters (i.e., dissolved oxygen) state that a stream is not impaired if <10% of the samples (i.e., sample size 20 or more samples) exceed criteria (SDDENR, 2008). As stated earlier, during the 6-year period 2004 through 2007 and 2009, 2,982 hourly

measurements of dissolved oxygen were recorded in the powerplant in August. Of these measurements, 546 (18%) were less than South Dakota's 5 mg/l minimum dissolved oxygen water quality standards' criterion for the protection of Warmwater Permanent Fish Life Propagation. However, less than 10 percent of the hourly dissolved oxygen measurements exceeded the criteria on an annual basis. Given that the Fort Randall tailwaters is not a lake, South Dakota's 303(d) impairment criteria for lakes states that a lake is considered fully supporting the aquatic life beneficial use if profile data indicate a region within the water column where temperature, pH, and dissolved oxygen meet numeric water quality standards criteria (SDDENR, 2008). At all times during the tailwaters monitoring (i.e., July 17; and August 3, 5, 10, 12, 17, 19, 24, and 26) a region existed within the tailwaters area where temperature, pH, and dissolved oxygen met numeric water quality standards criteria. The State of South Dakota has the final determination as to whether or not the monitored dissolved oxygen conditions in the Fort Randall tailwaters indicate impairment of the designated Warmwater Permanent Fish Life Propagation beneficial use.

FISH KILL POTENTIAL

Warmwater species can generally tolerate dissolved oxygen levels down to 3 mg/l for short periods of time. A fish kill could occur if dissolved oxygen levels quickly dropped to 3 mg/l or below and fish were trapped with no escaped routes. This does not appear to be the situation at the Fort Randall tailwaters – escape routes are present. As dissolved oxygen levels fall below 5 mg/l, fish can move to areas of “refugia” where dissolved oxygen levels are higher. In the Fort Randall tailwaters refugia could be provided by moving to the west bank, downstream, into the spillway, or into the west embayment off the tailwaters. Organisms that lack the ability to move rapidly (e.g., macroinvertebrates) could be impacted to a greater extent by low dissolved oxygen levels in the tailwaters; however, macroinvertebrates have the ability to rapidly re-colonize any impacted areas.

Summer thermal stratification and hypolimnetic hypoxia have historically occurred in Lake Francis Case. These conditions seemingly have resulted in past low dissolved oxygen conditions in the Fort Randall tailwaters. The District is unaware of any past fish kills that have occurred in the Fort Randall tailwaters that could be attributed to low dissolved oxygen conditions during the summer.

CONCLUSIONS

Thermal stratification of Lake Francis Case during the summer results in the development of hypoxic conditions in the reservoir's hypolimnion. Lake Francis Case is a bottom-release reservoir, and hypoxic water is passed through Fort Randall Dam during power production during July and August. Under these conditions, dissolved oxygen levels in areas of the Fort Randall Dam tailwaters fall below South Dakota's water quality standards' minimum dissolved oxygen criterion of 5 mg/l. Monitored conditions indicate that the low dissolved oxygen levels in the tailwaters are not seemingly impairing the designated Warmwater Permanent Fish Life Propagation beneficial use as regions of refugia exist in the impacted area. Also, there is no evidence of past fish kills in the Fort Randall tailwaters attributable to hypoxic conditions. If warranted, dissolved oxygen conditions in the Fort Randall tailwaters during periods of hypoxic dam releases could be mitigated by drawing water from the reservoir surface spilling it down the spillway.

REFERENCES

South Dakota Department of Environment and Natural Resources. 2008. The 2008 South Dakota integrated reports for surface water quality assessment. South Dakota Department of Environment and Natural Resources. Pierre, South Dakota.

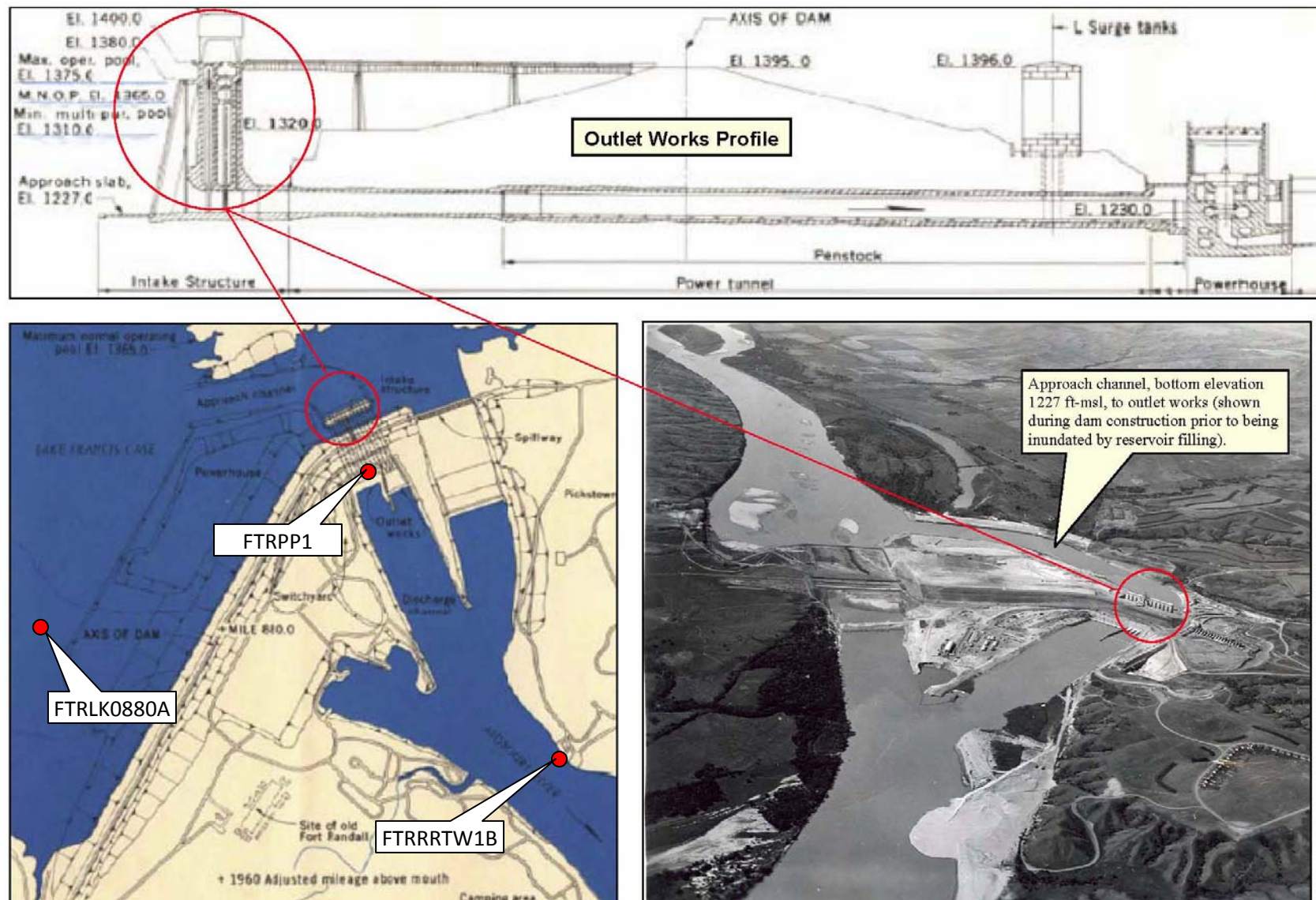


Figure 1. Schematic drawing and photo of outlet works at Fort Randall Dam. Water quality monitoring sites shown in lower left diagram.

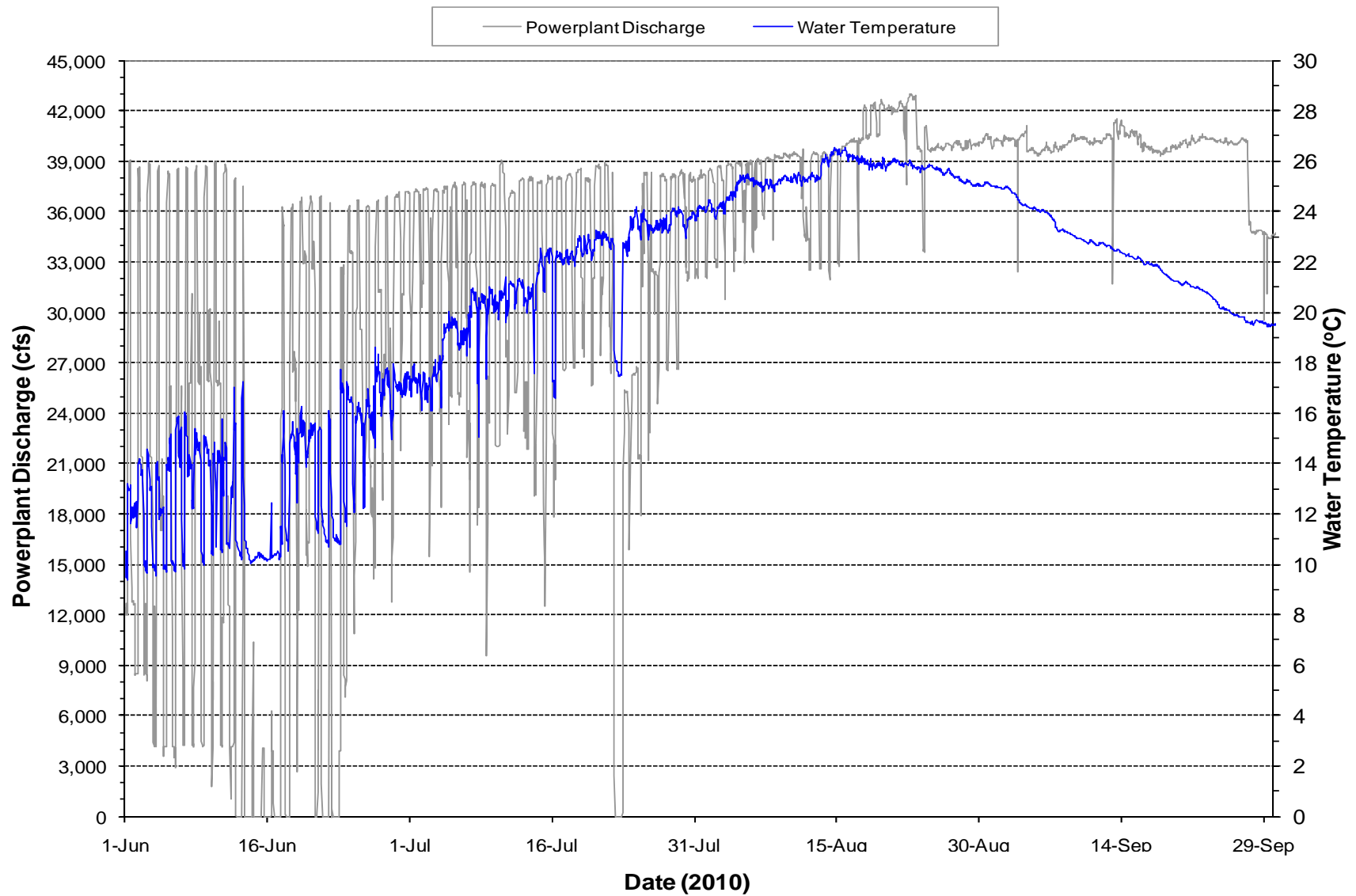


Figure 2. Hourly powerplant discharge and water temperature monitored in the Fort Randall powerplant “raw water” supply line during the period June 1 through September 30, 2010.

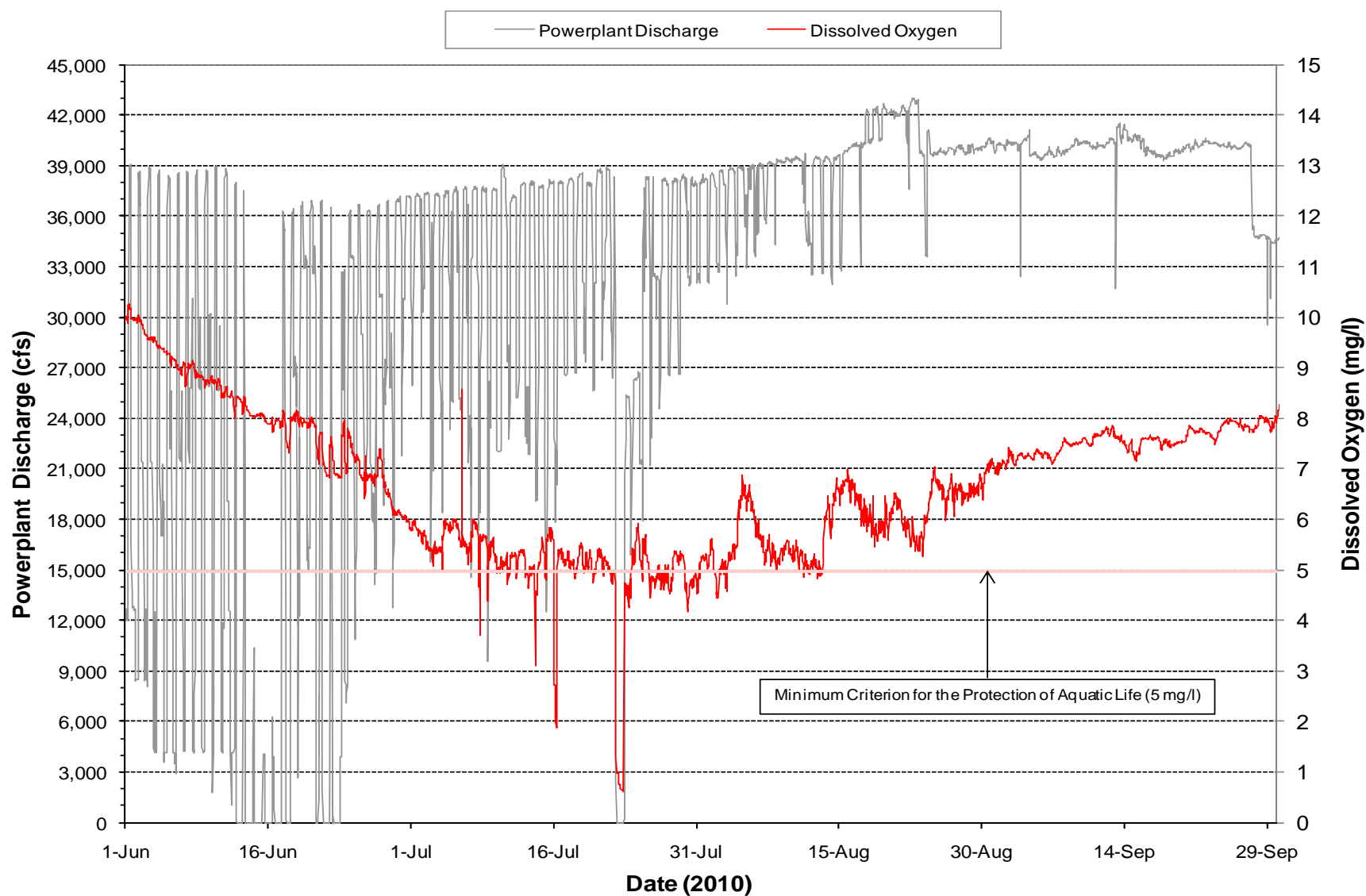


Figure 3. Hourly powerplant discharge and dissolved oxygen monitored in the Fort Randall powerplant “raw water” supply line during the period June 1 through September 30, 2010.

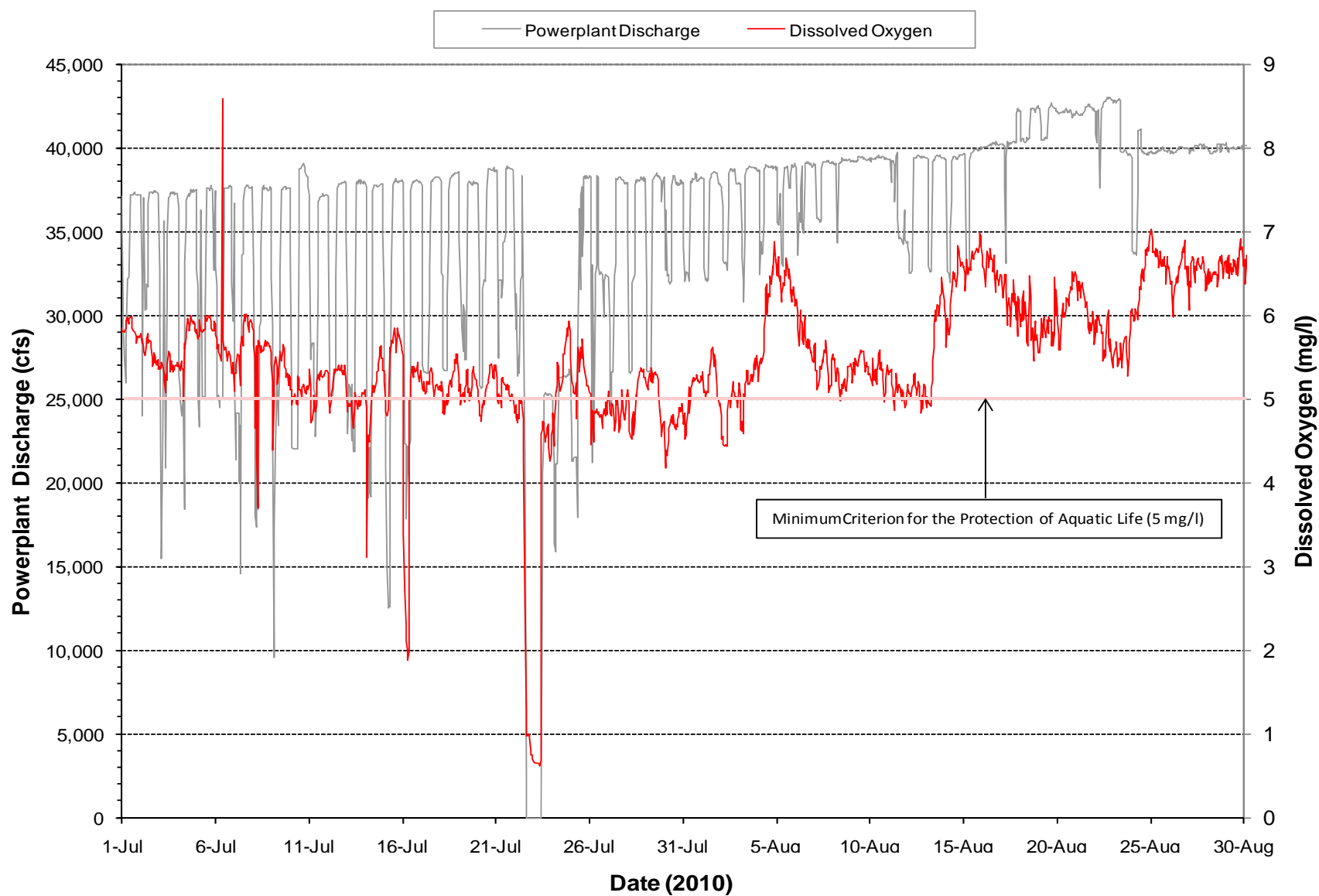


Figure 4. Hourly powerplant discharge and dissolved oxygen monitored in the Fort Randall powerplant “raw water” supply line during the period July 1 through August 30, 2010.

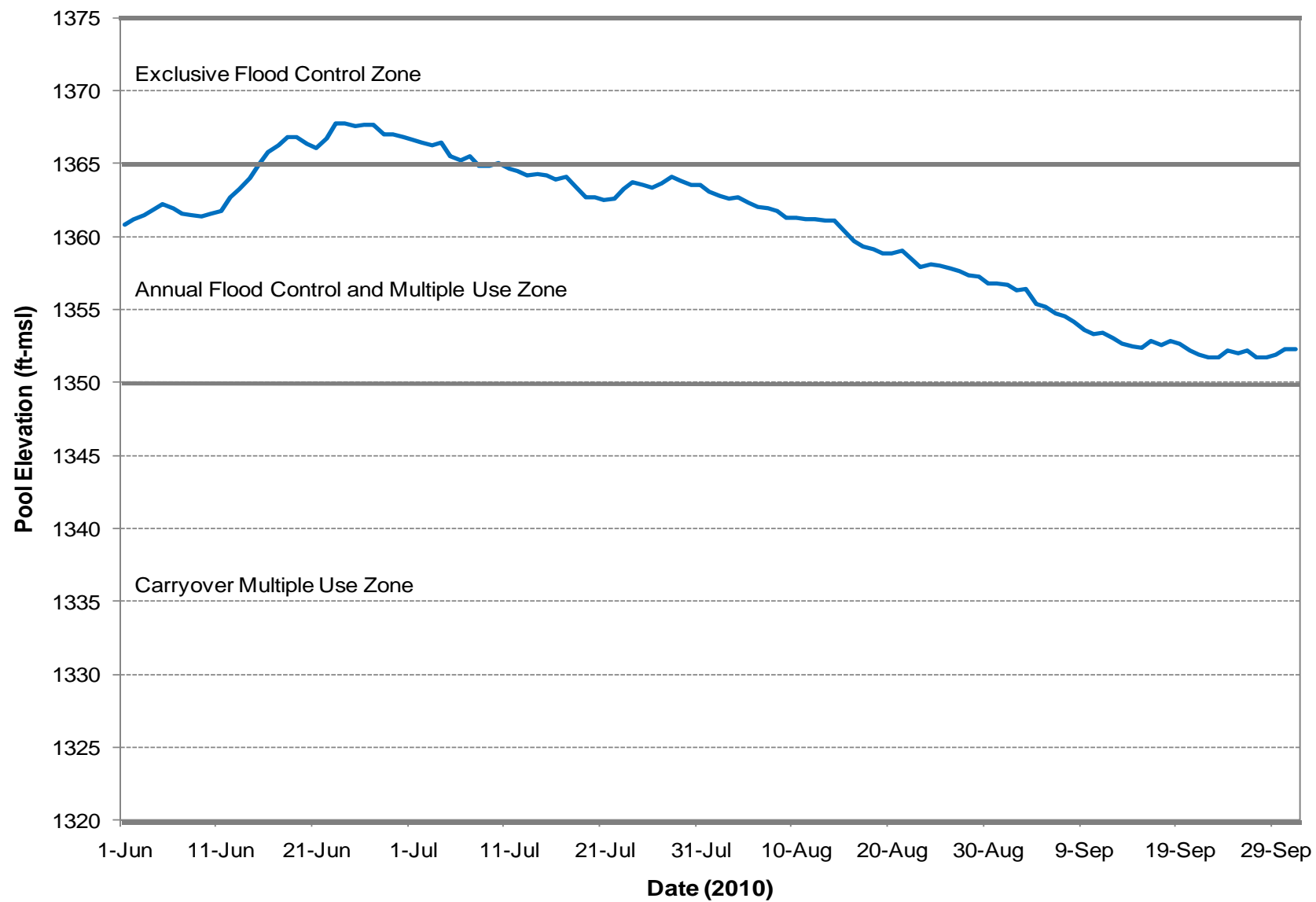


Figure 5. Lake Francis Case midnight pool levels June 1 through October 1, 2010.

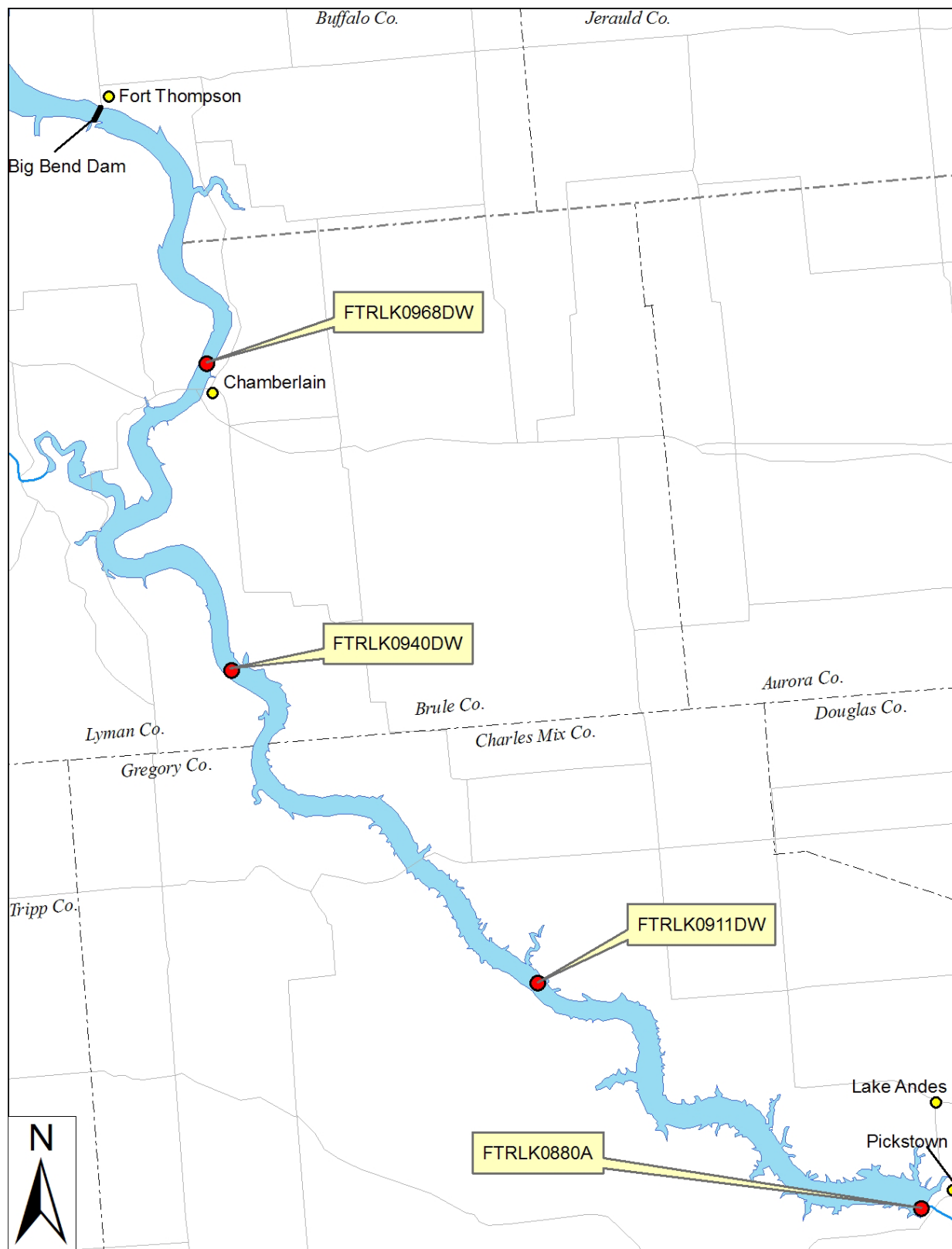


Figure 6. Ambient water quality monitoring station locations on Lake Francis Case.

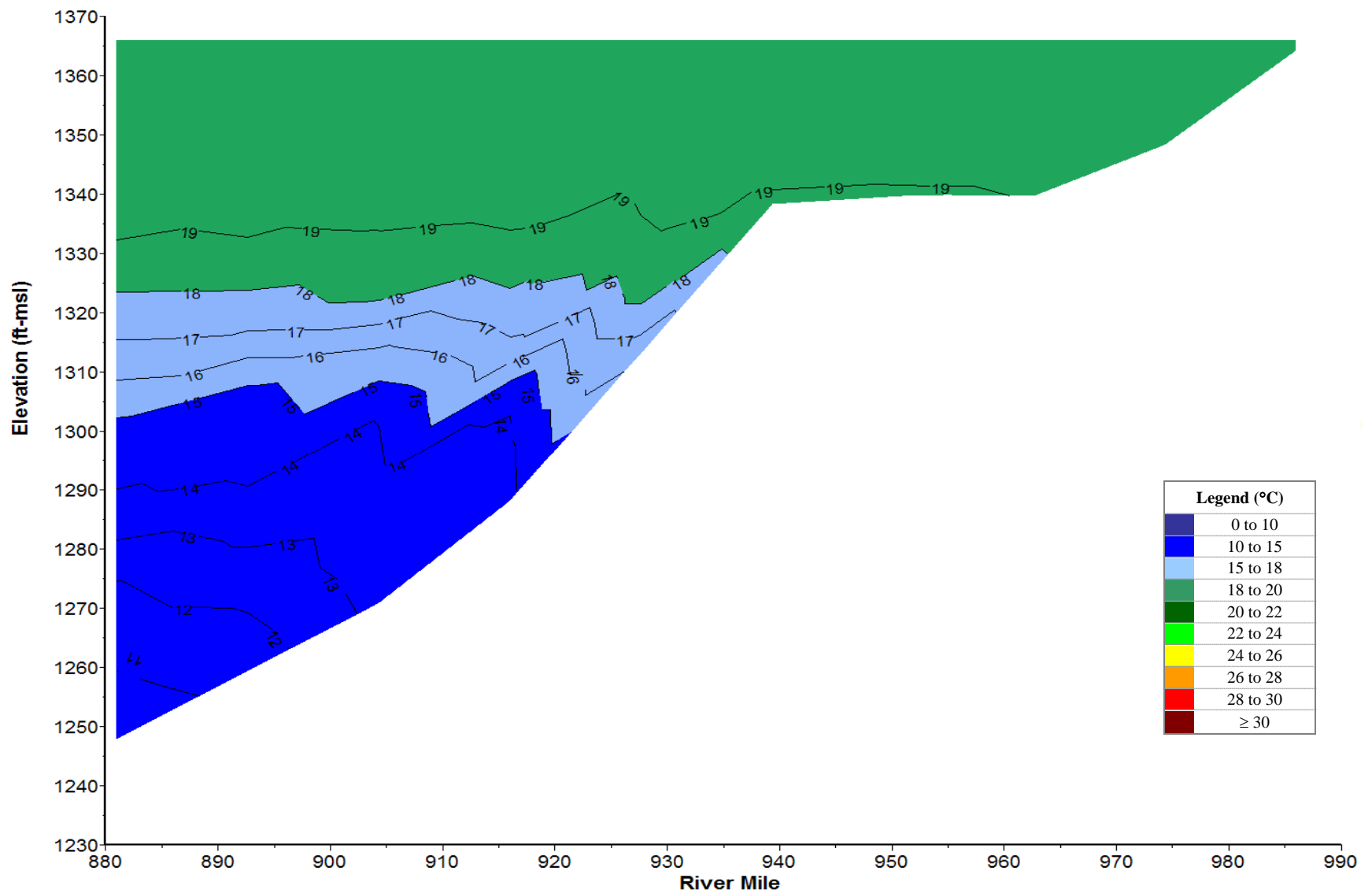


Figure 7. Longitudinal water temperature contour plot of Lake Francis Case based on depth-profile water temperatures measured at RM880, RM911, RM 940, and RM968 on June 17, 2010.

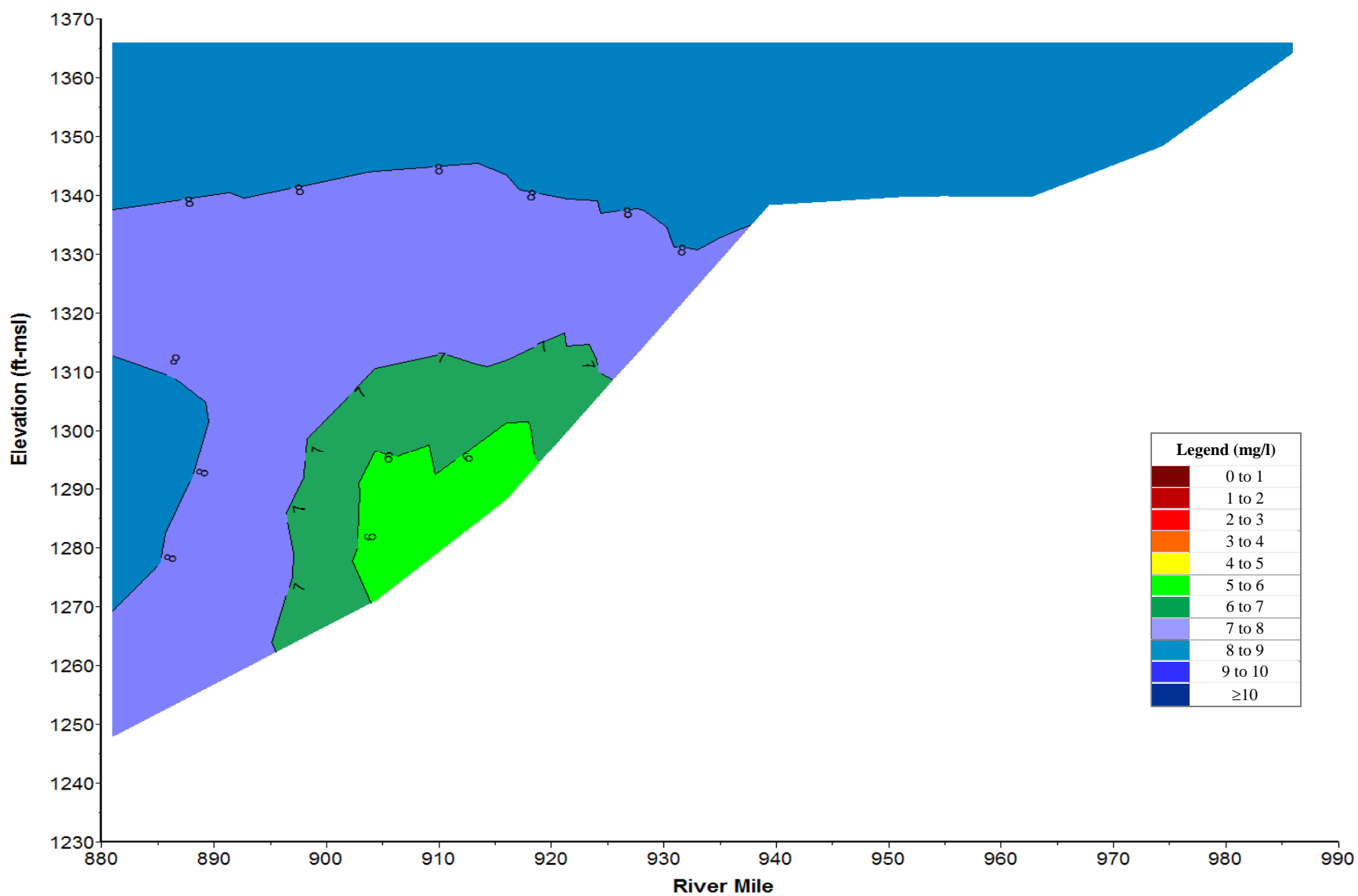


Figure 8. Longitudinal dissolved oxygen contour plot of Lake Francis Case based on depth-profile dissolved oxygen levels measured at RM880, RM911, RM 940, and RM968 on June 17, 2010.

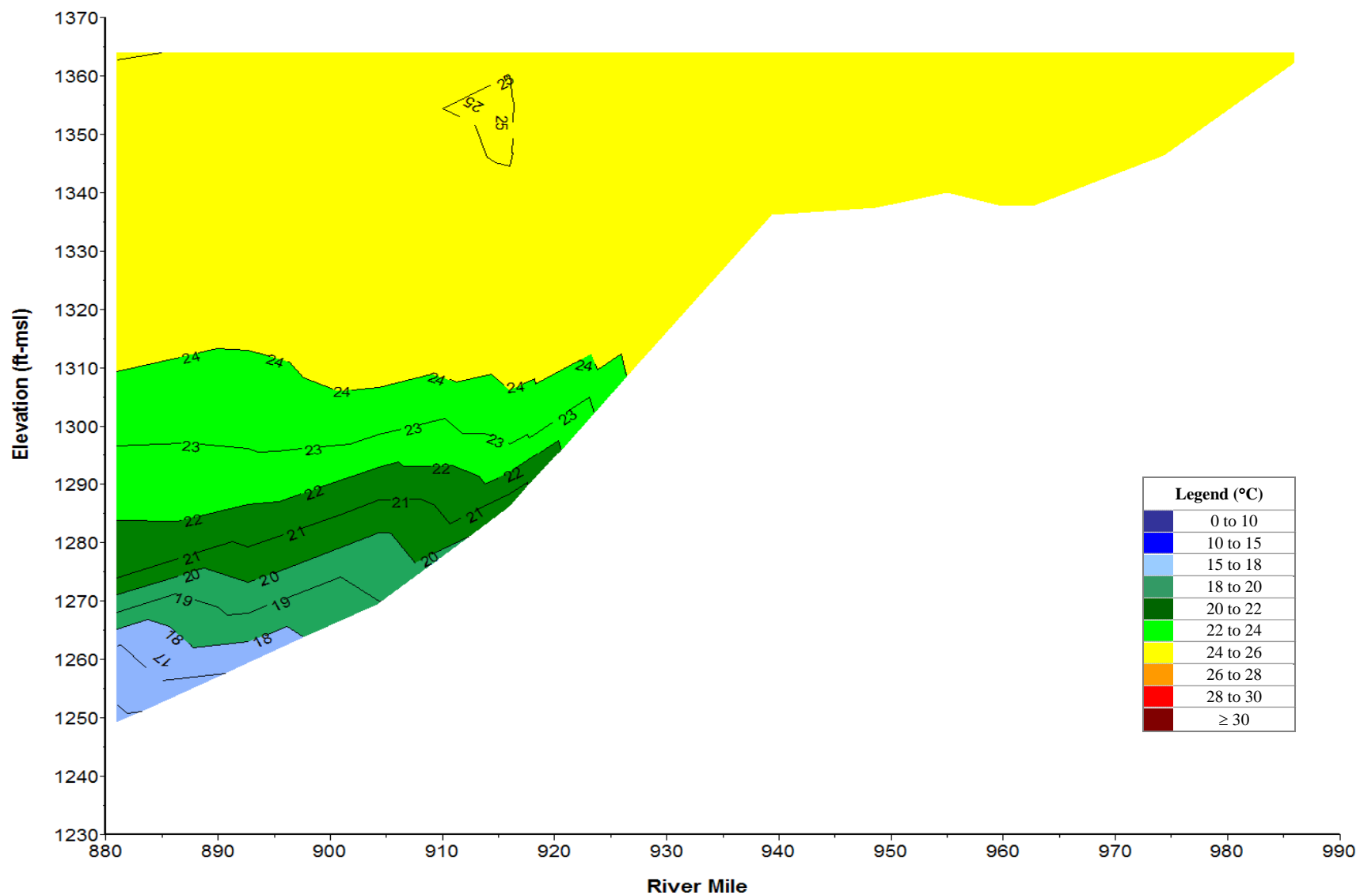


Figure 9. Longitudinal water temperature contour plot of Lake Francis Case based on depth-profile water temperatures measured at RM880, RM911, RM 940, and RM968 on July 15, 2010.

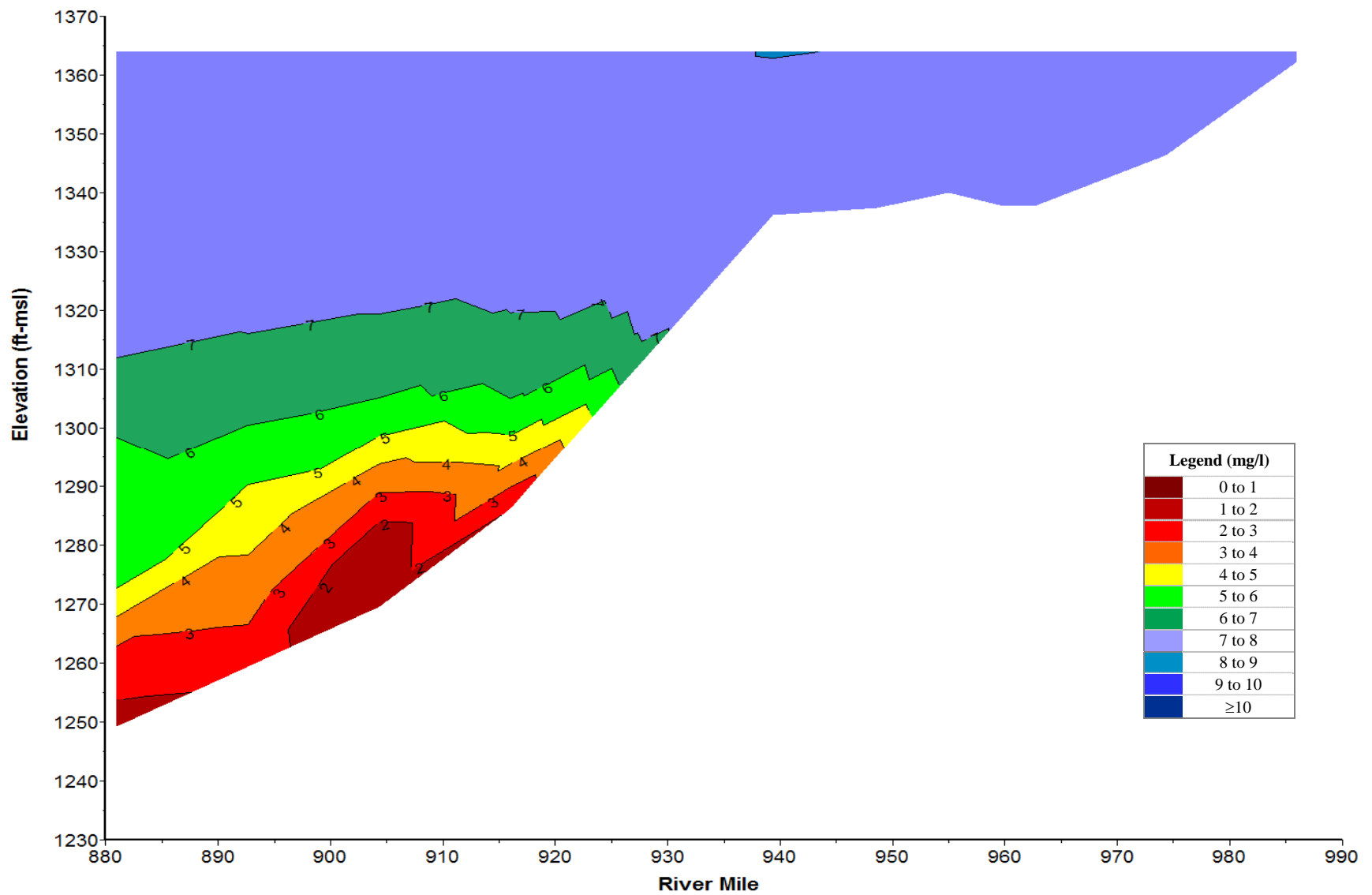


Figure 10. Longitudinal dissolved oxygen contour plot of Lake Francis Case based on depth-profile dissolved oxygen levels measured at RM880, RM911, RM 940, and RM968 on July 15, 2010.

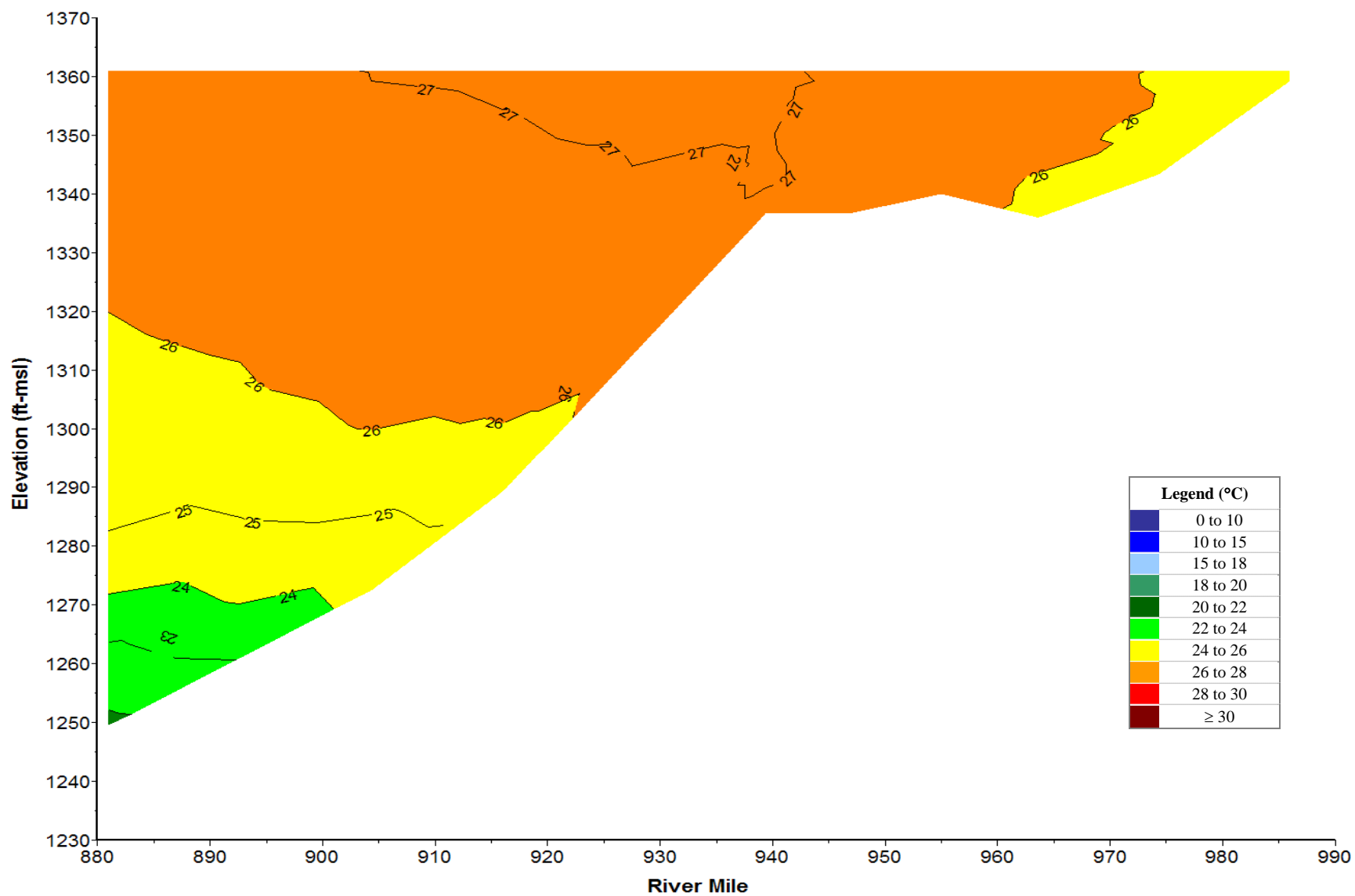


Figure 11. Longitudinal water temperature contour plot of Lake Francis Case based on depth-profile water temperatures measured at RM880, RM911, RM 940, and RM968 on August 12, 2010.

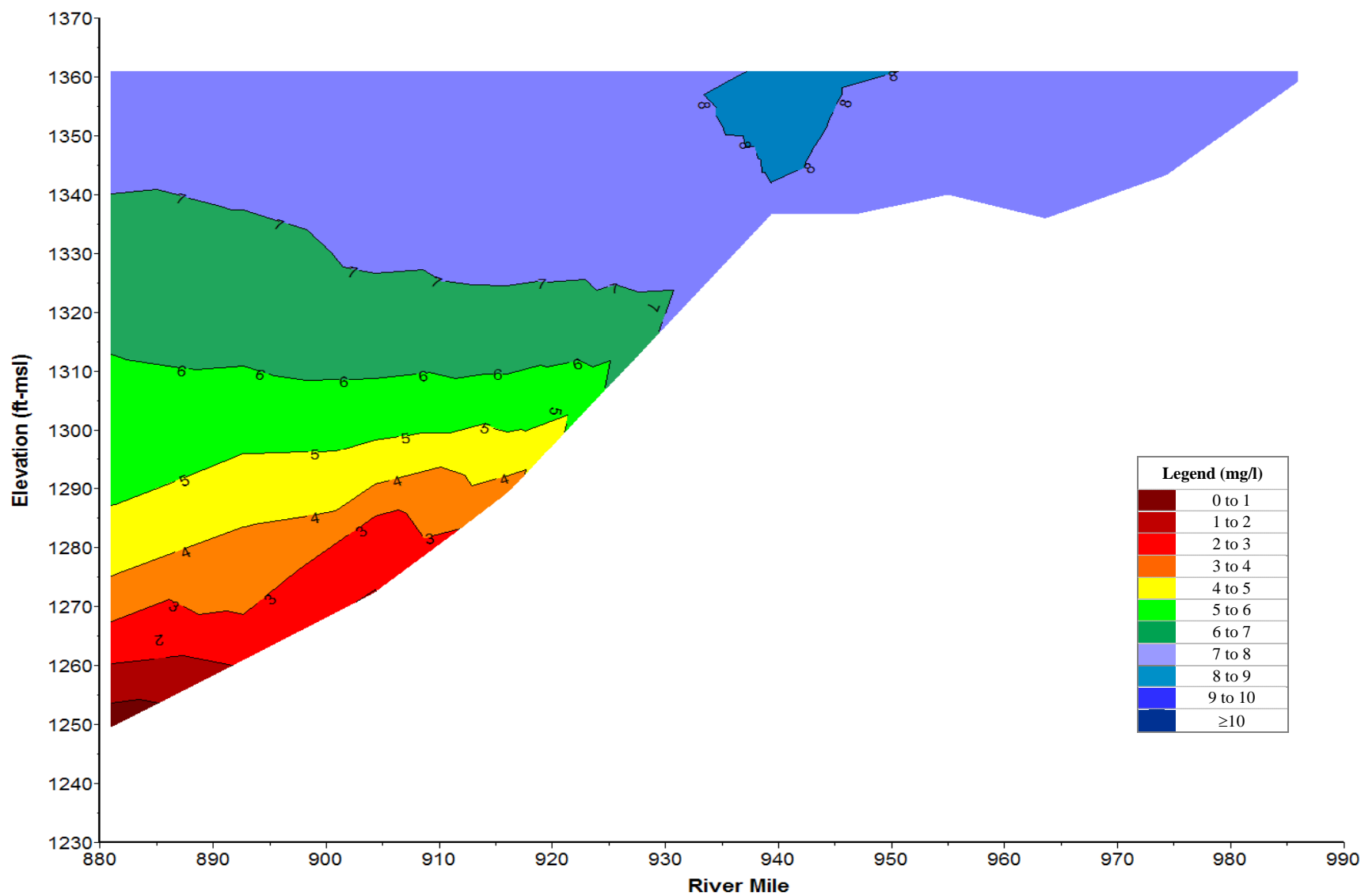


Figure 12. Longitudinal dissolved oxygen contour plot of Lake Francis Case based on depth-profile dissolved oxygen levels measured at RM880, RM911, RM 940, and RM968 on August 12, 2010.

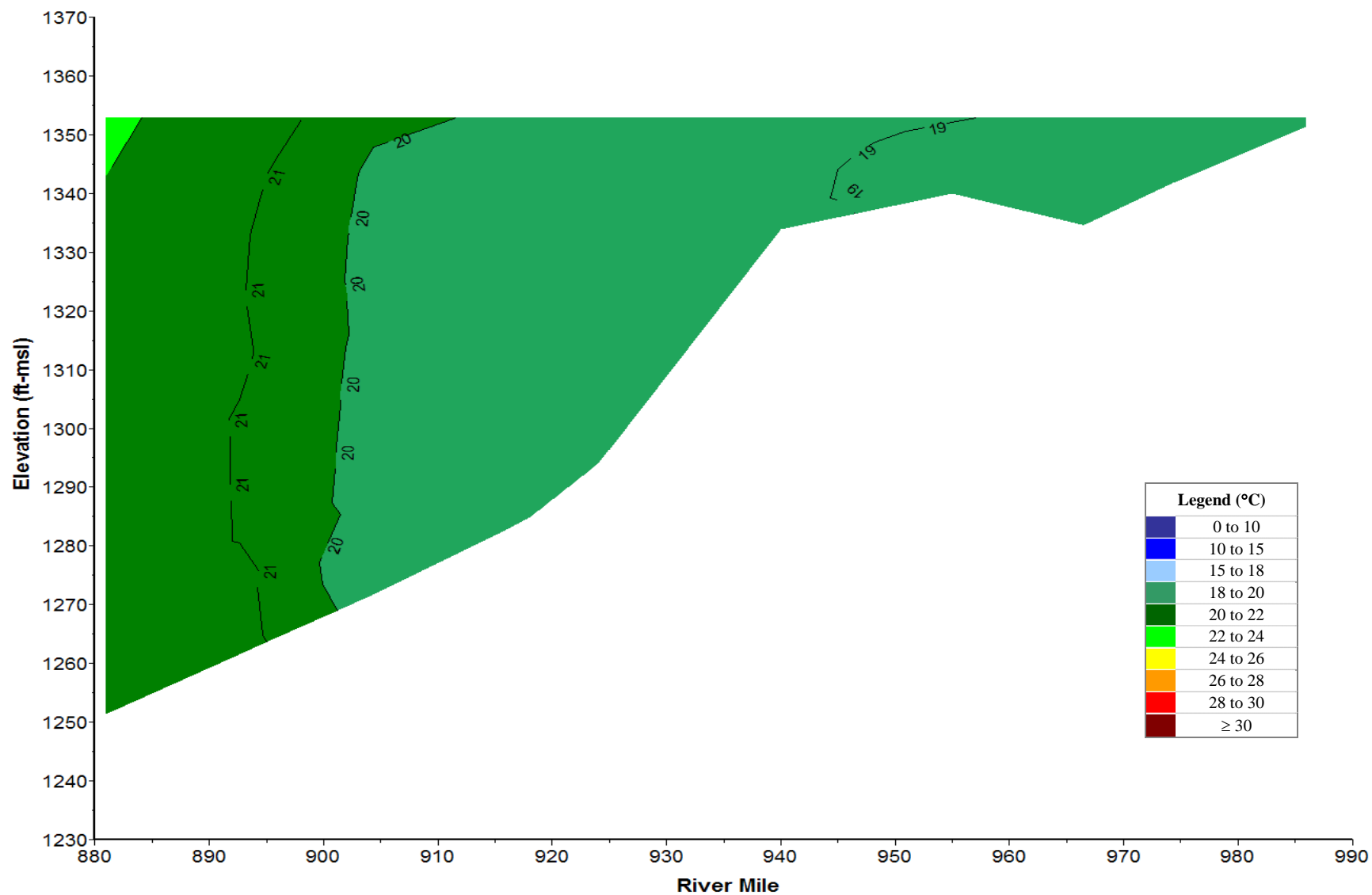


Figure 13. Longitudinal water temperature contour plot of Lake Francis Case based on depth-profile water temperatures measured at RM880, RM911, and RM968 on September 16, 2010.

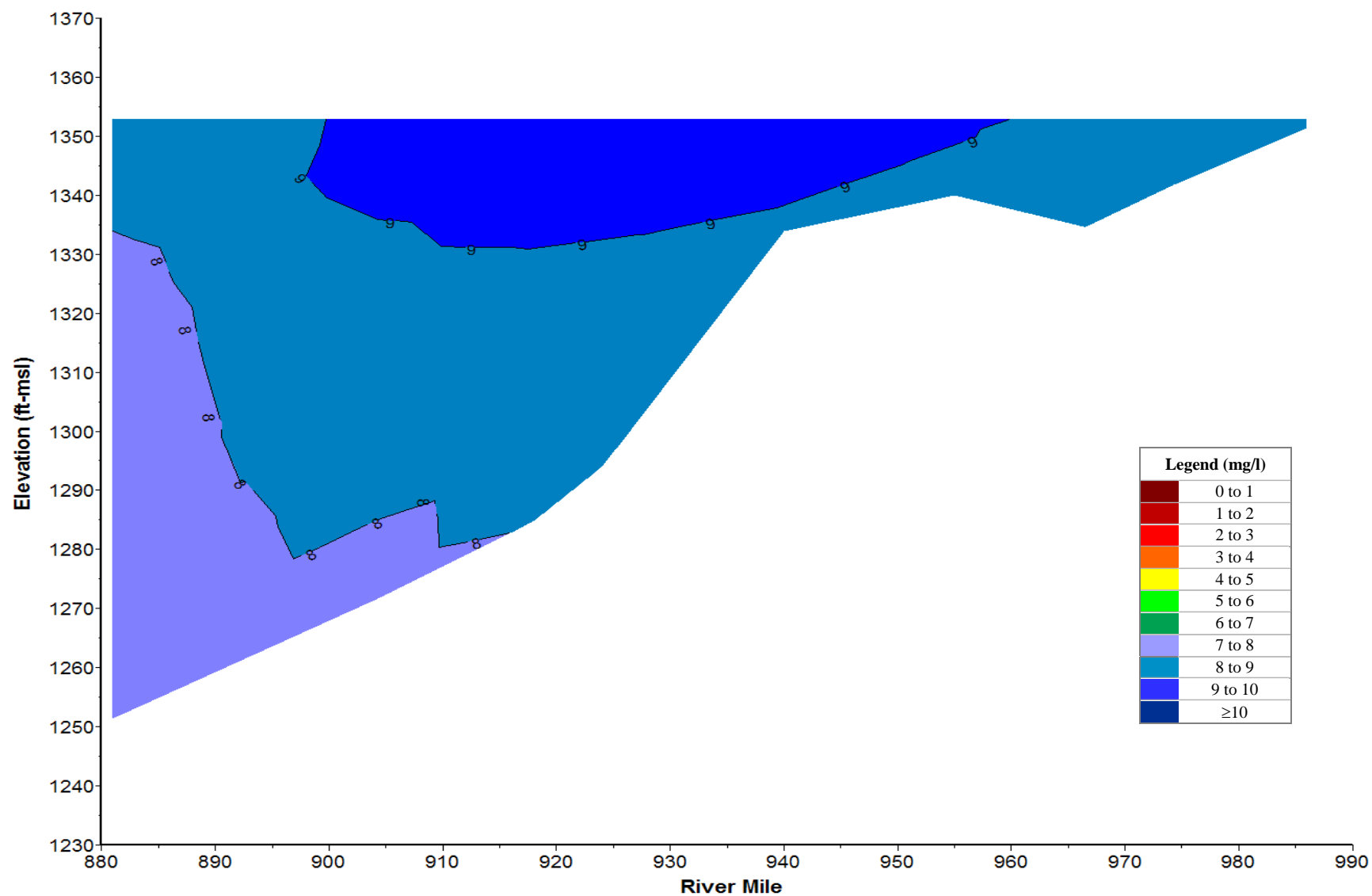


Figure 14. Longitudinal dissolved oxygen contour plot of Lake Francis Case based on depth-profile dissolved oxygen levels measured at RM880, RM911, and RM968 on September 16, 2010.

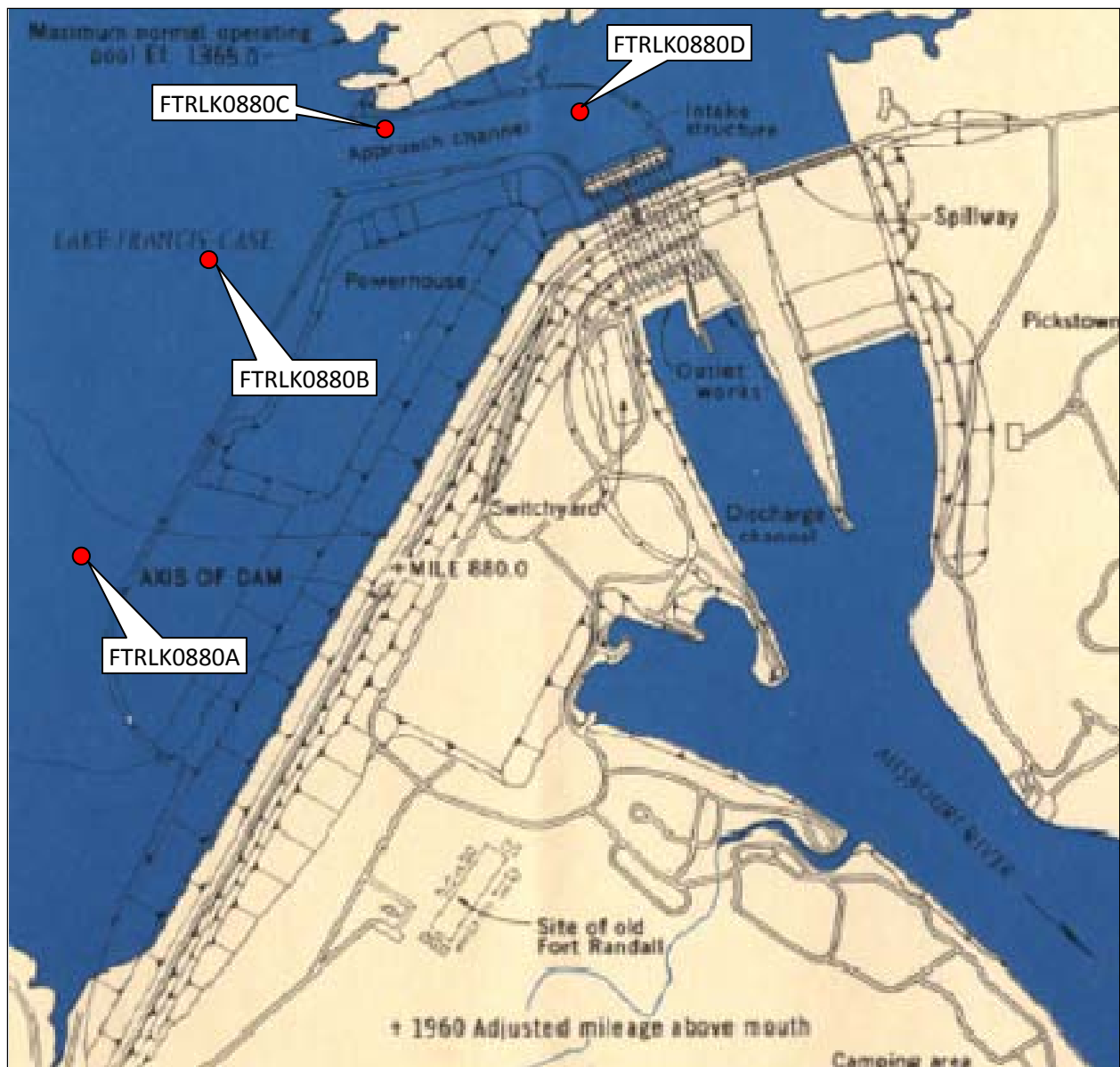


Figure 15. Location of sites monitored in Lake Francis Case on 19-August-2010 along Fort Randall Dam and the submerged approach channel to the intake structure.

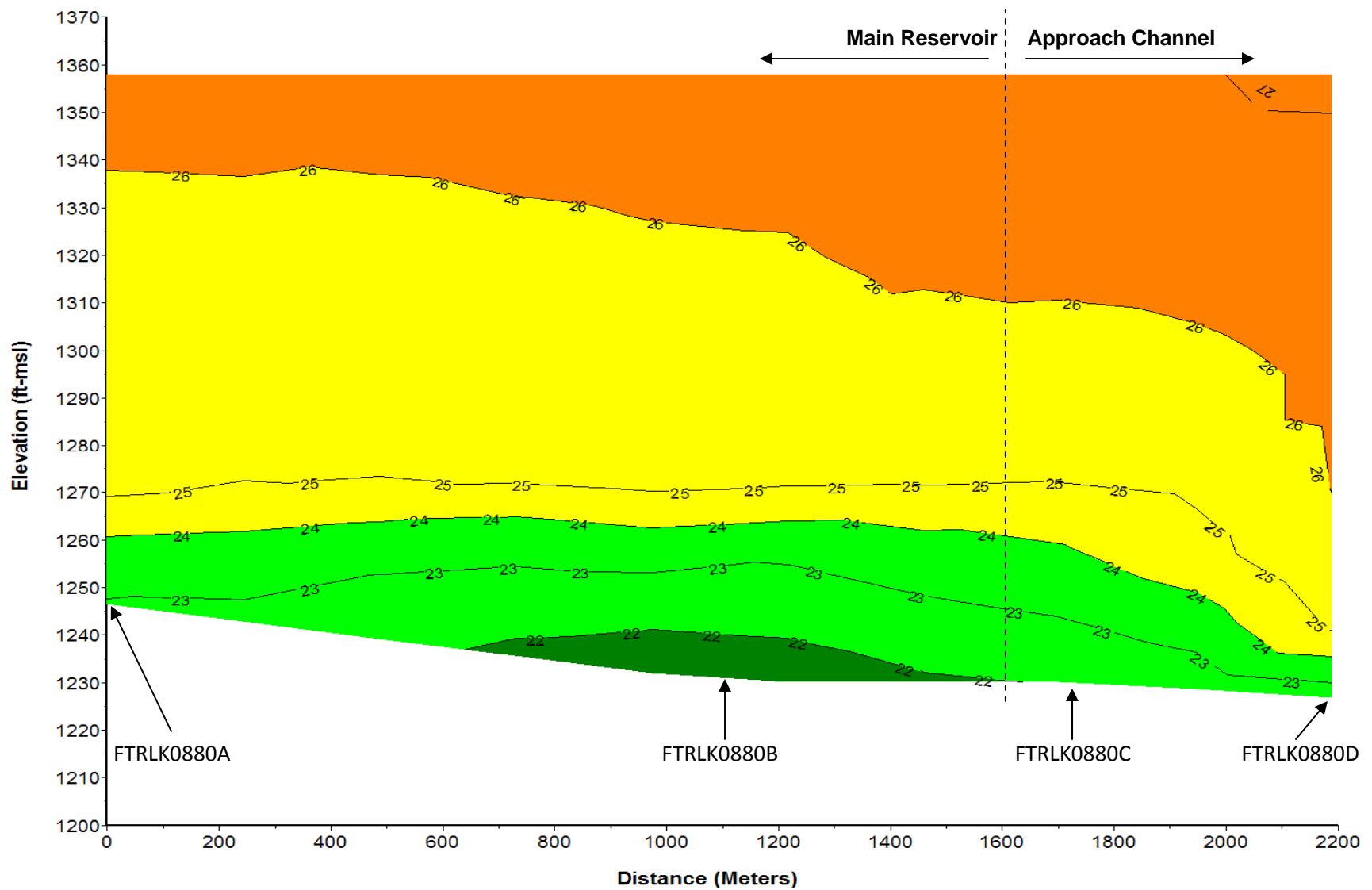


Figure 16. Contour plot of water temperature measured along Fort Randall Dam from monitoring site FTRLK0880A to site FTRLK0880D on August 19, 2010.

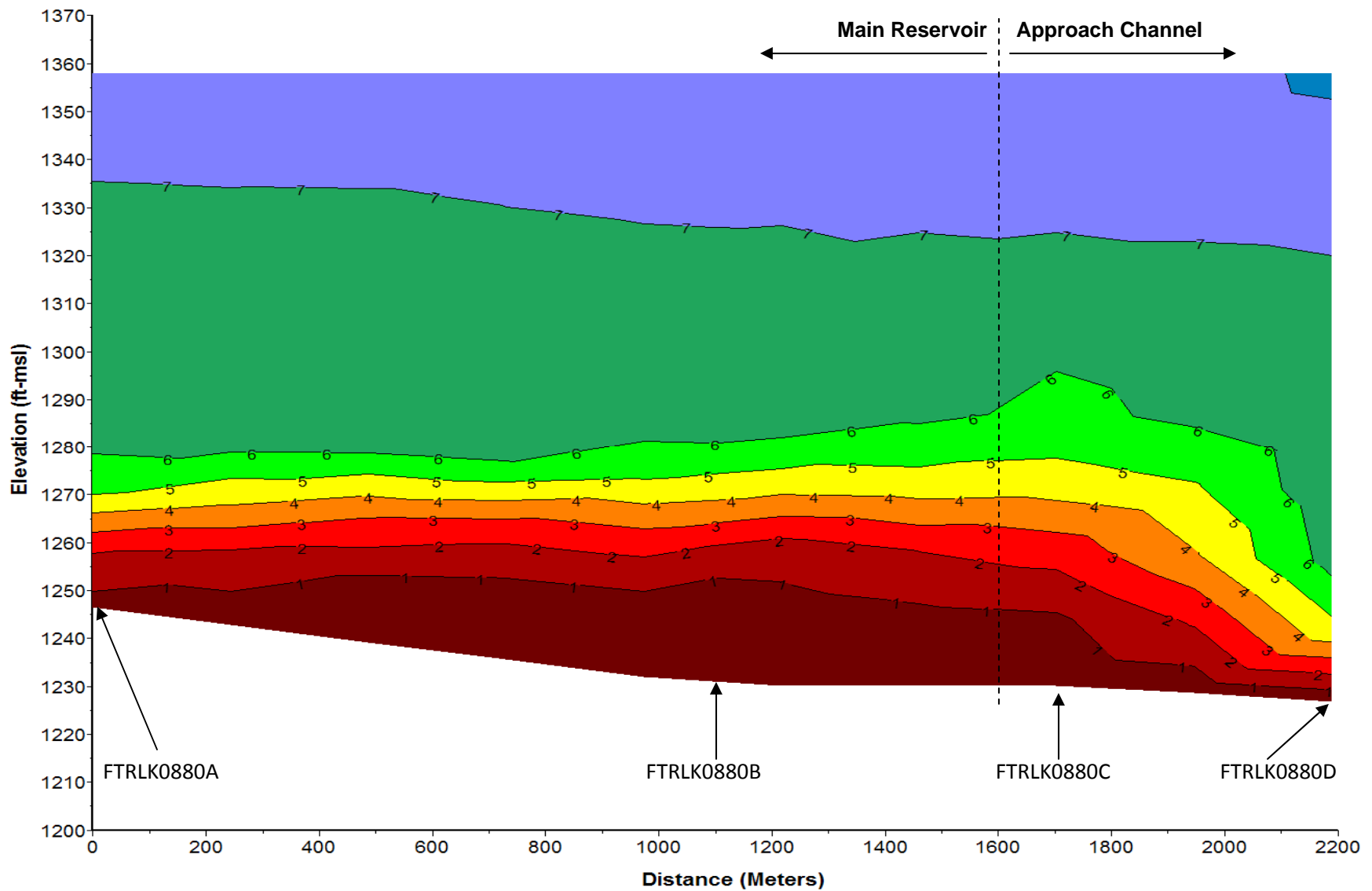


Figure 17. Contour plot of dissolved oxygen levels measured along Fort Randall Dam from monitoring site FTRLK0880A to site FTRLK0880D on August 19, 2010.

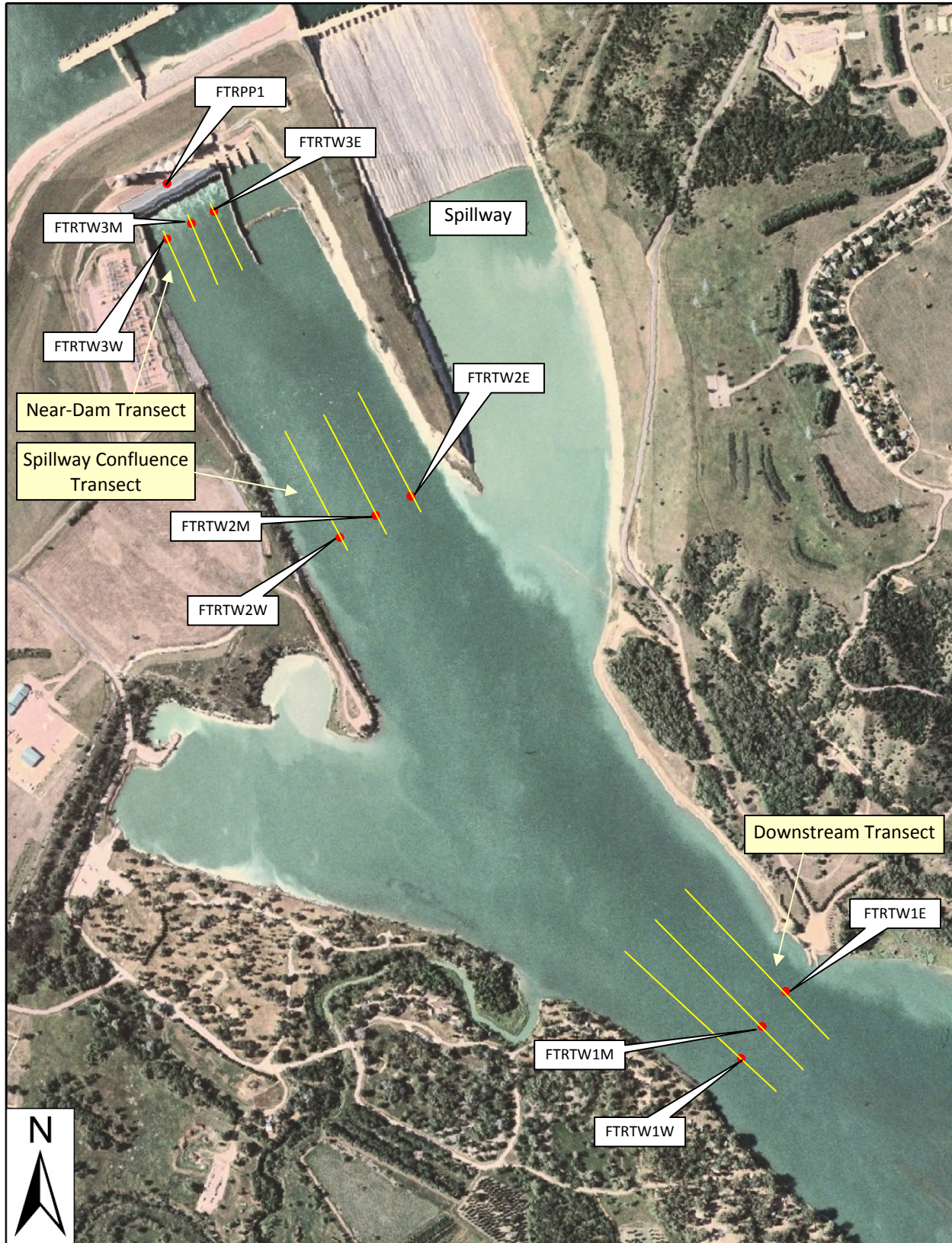


Figure 18. Investigative sites monitored in the Fort Randall Dam tailwaters.

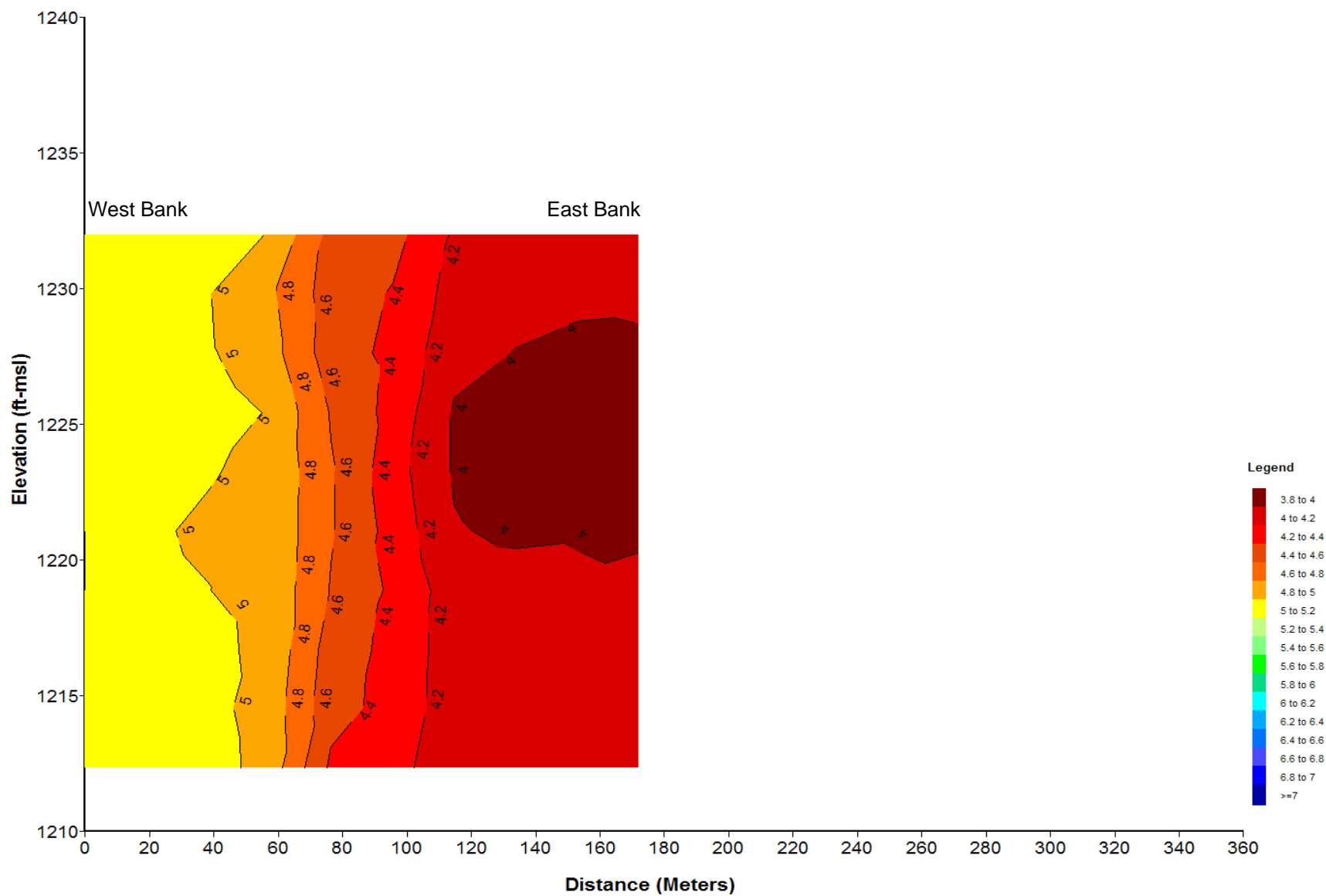


Figure 19. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on July 27, 2010.

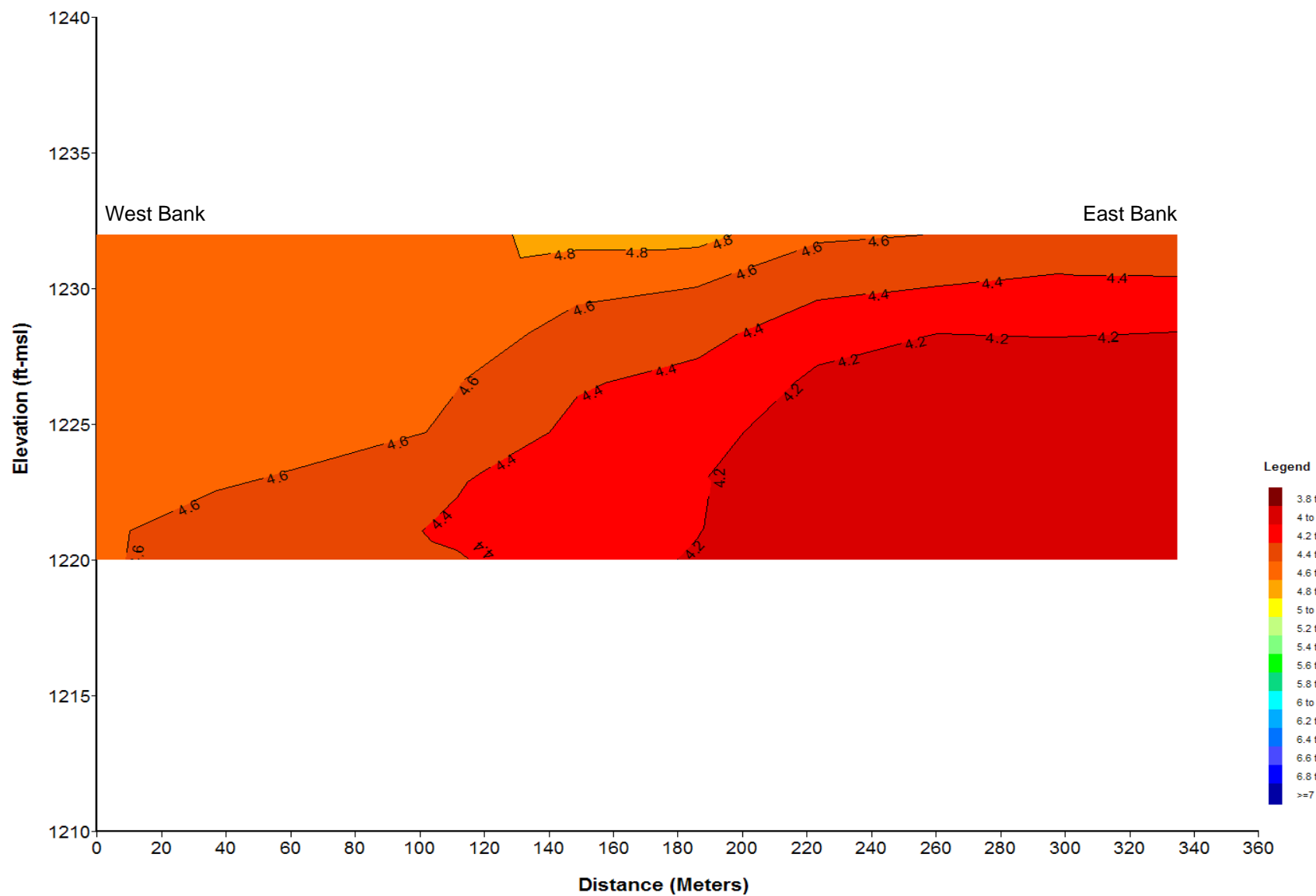


Figure 20. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on July 27, 2010.

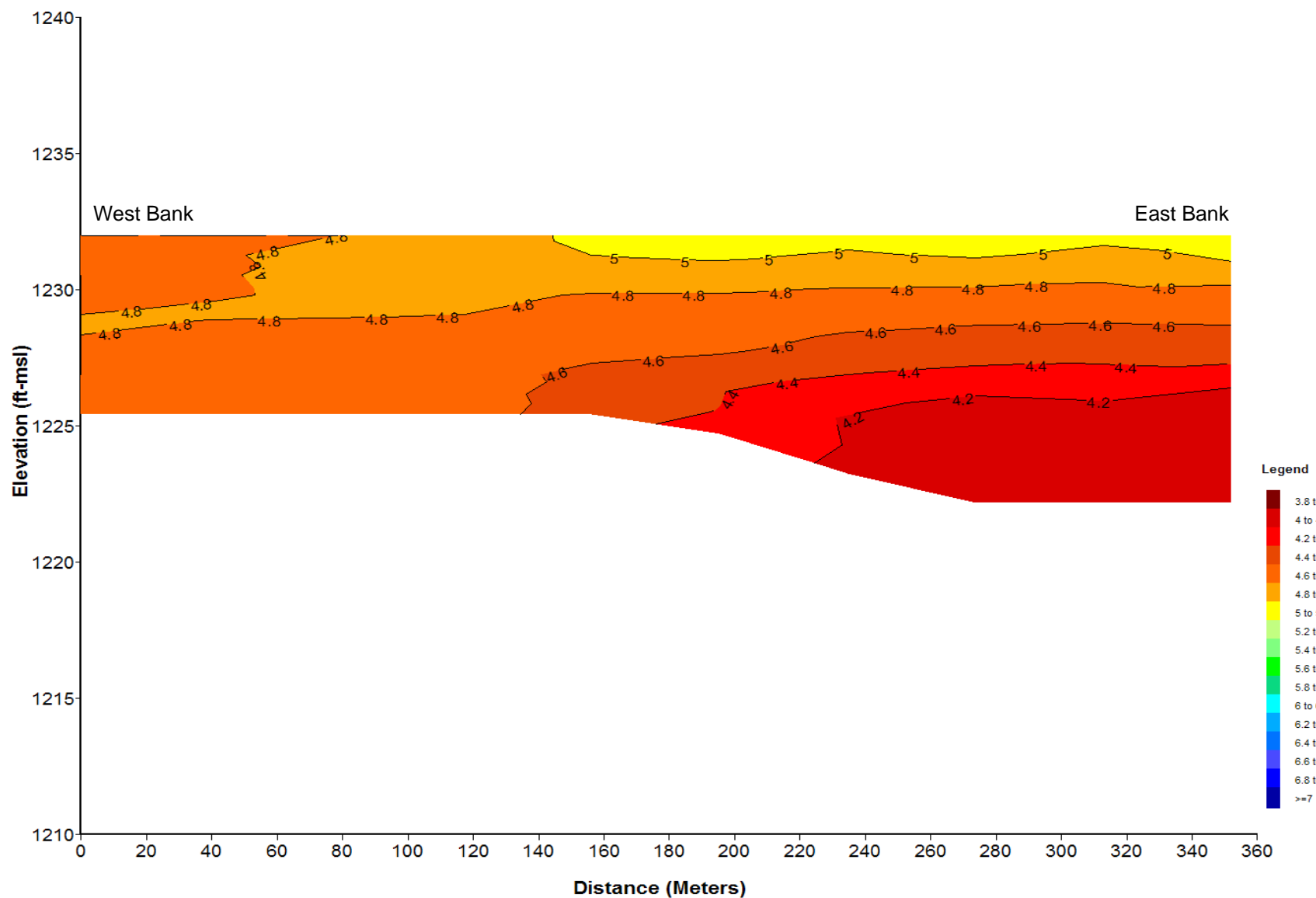


Figure 21. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on July 27, 2010.

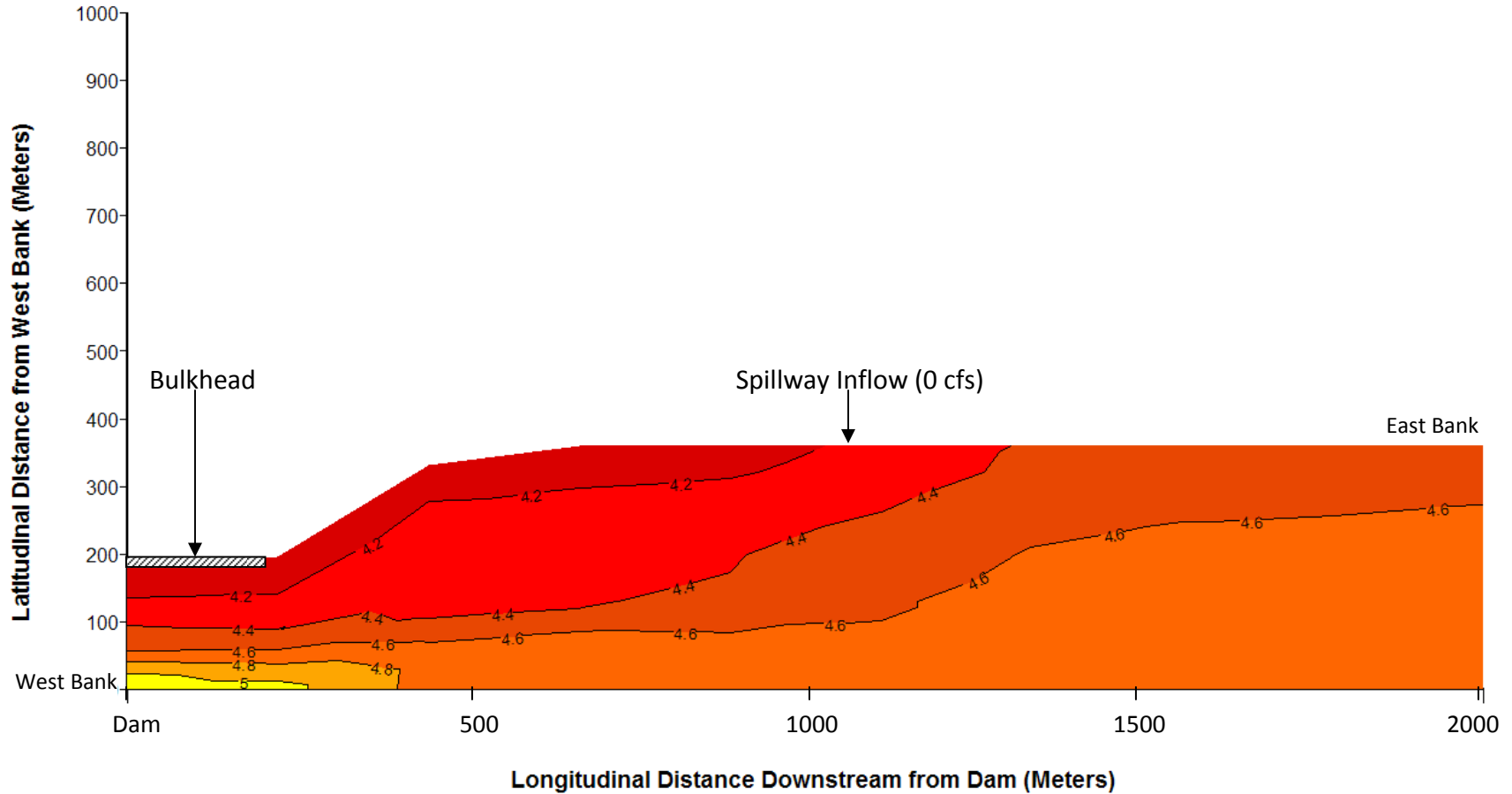


Figure 22. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on July 27, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

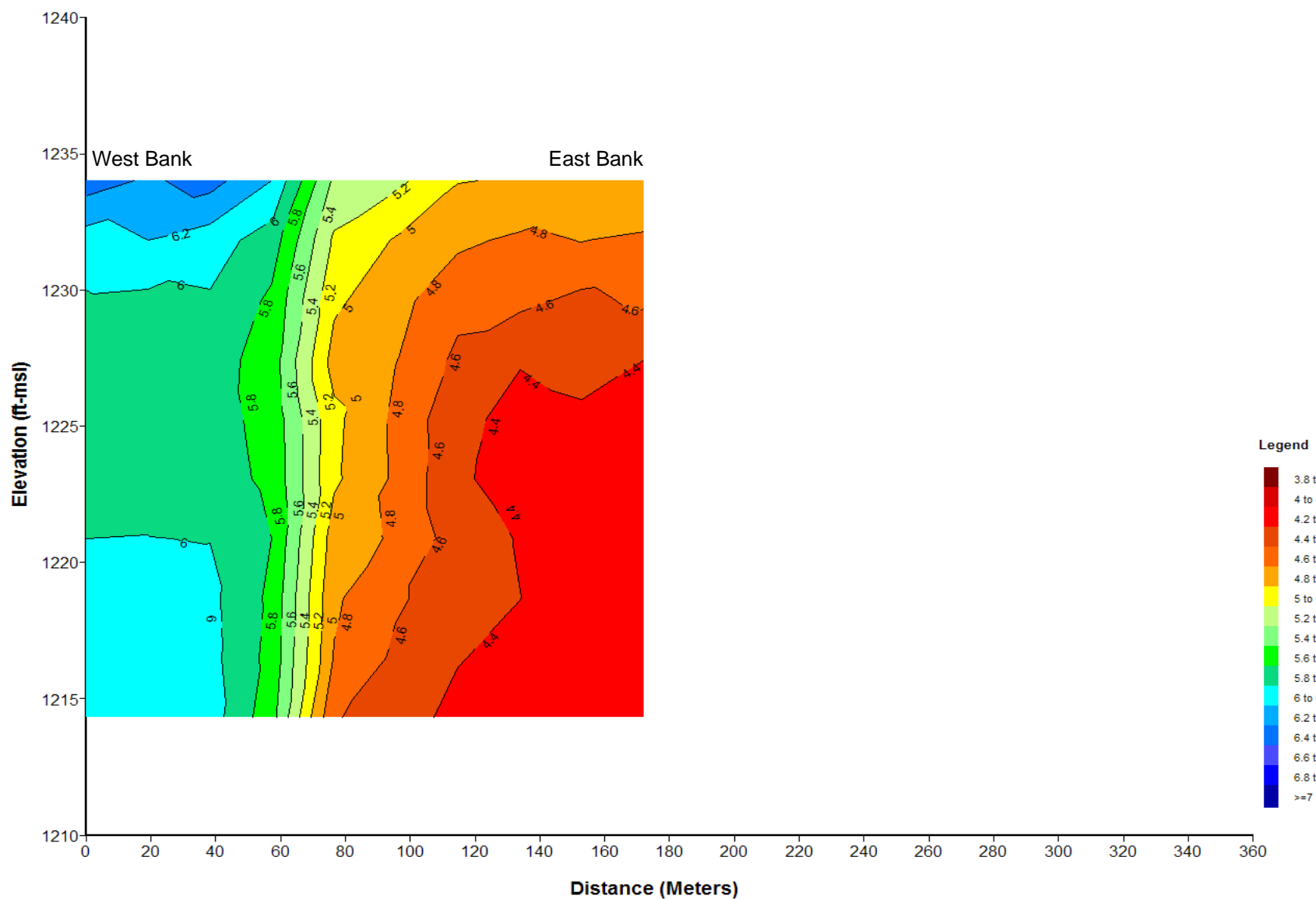


Figure 23. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 3, 2010.

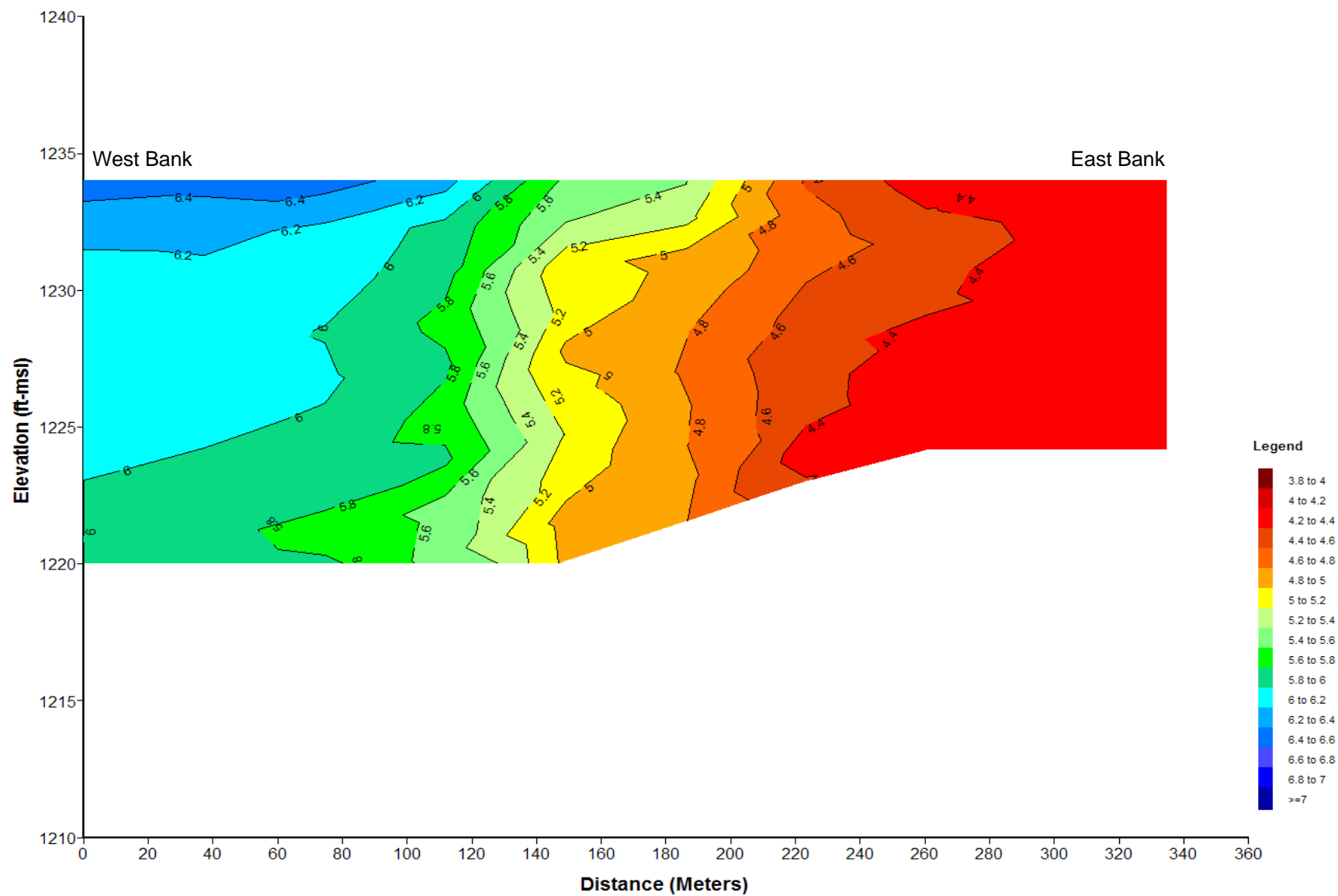


Figure 24 Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 3, 2010.

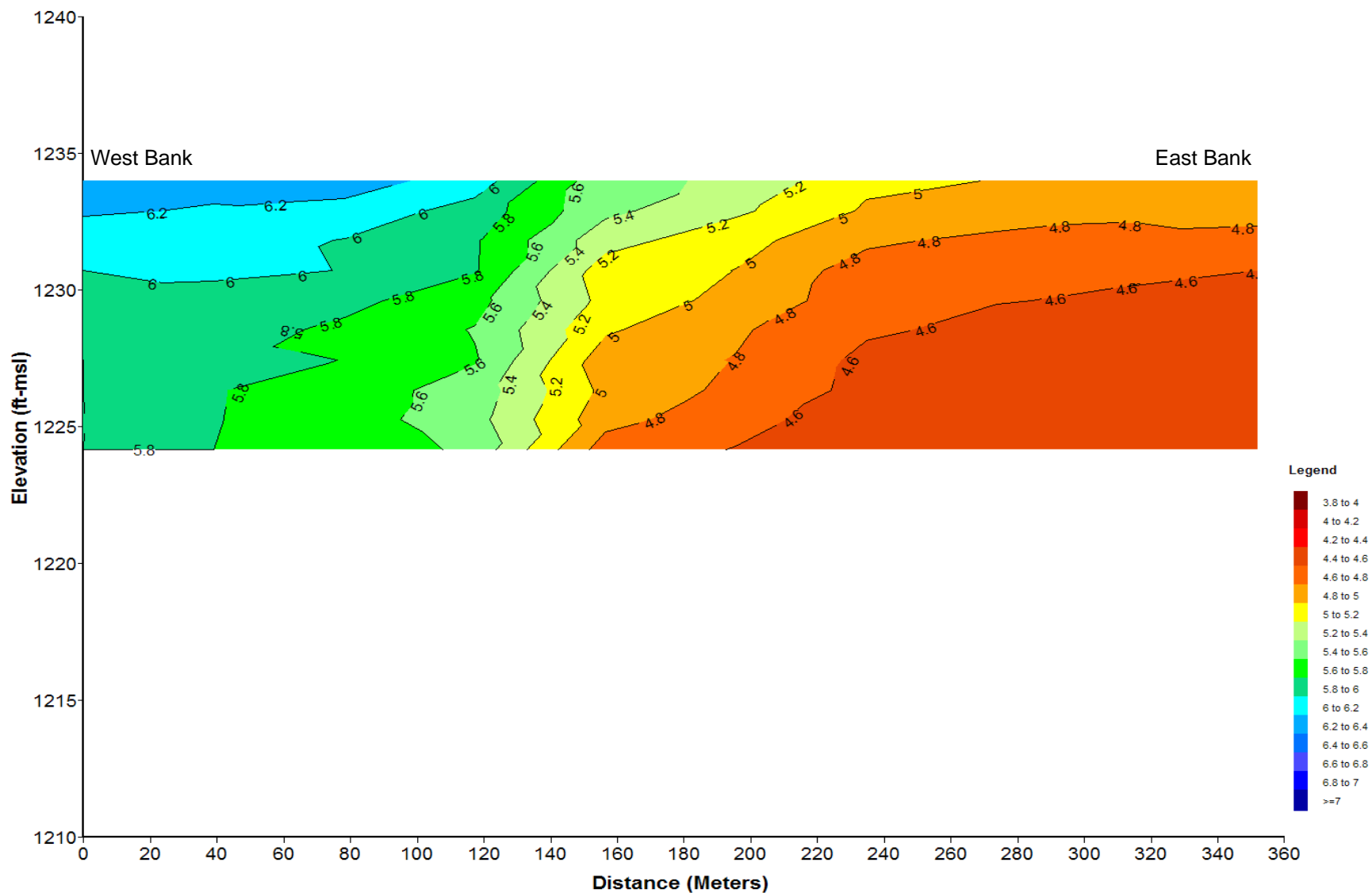


Figure 25. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 3, 2010.

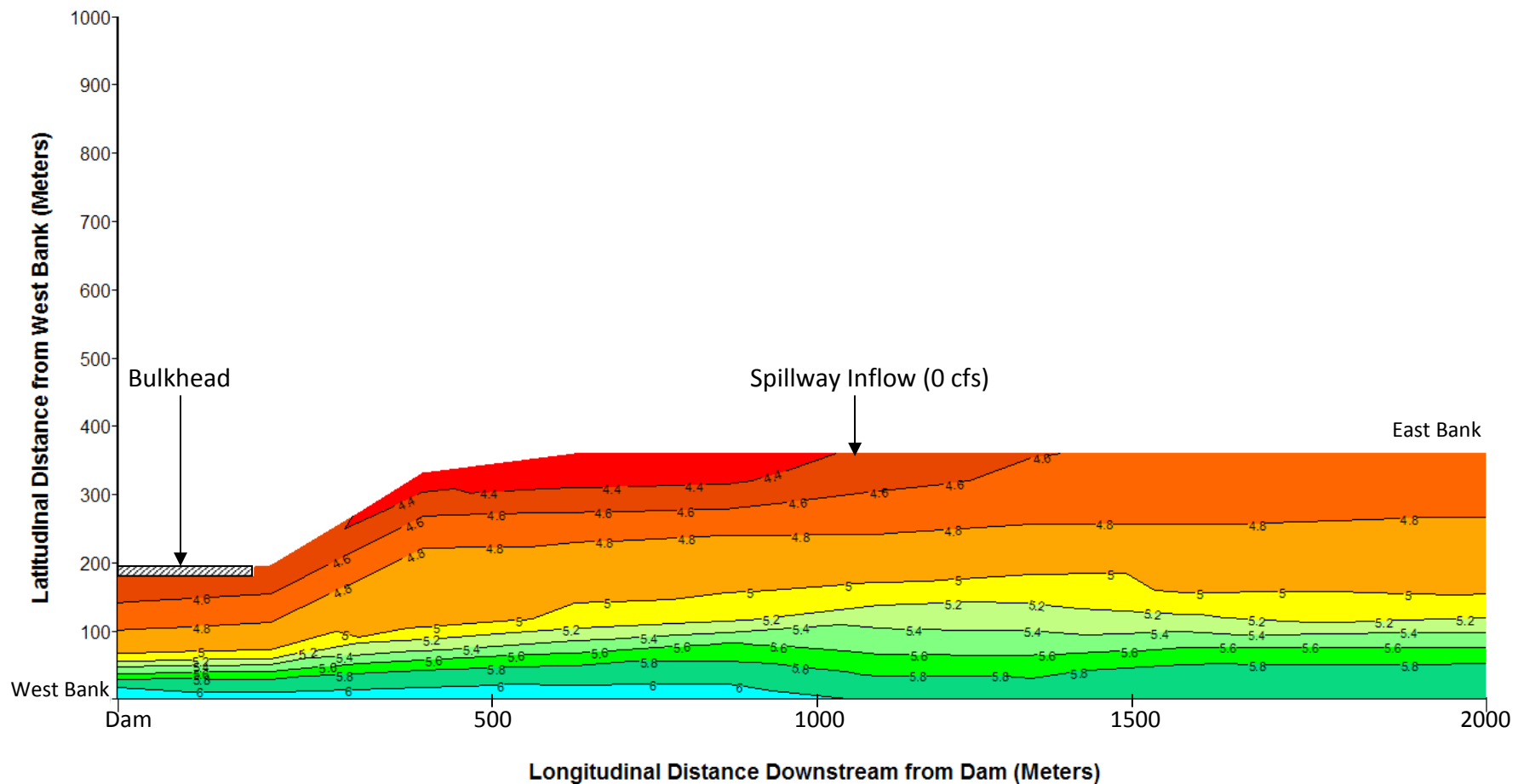


Figure 26. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 3, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

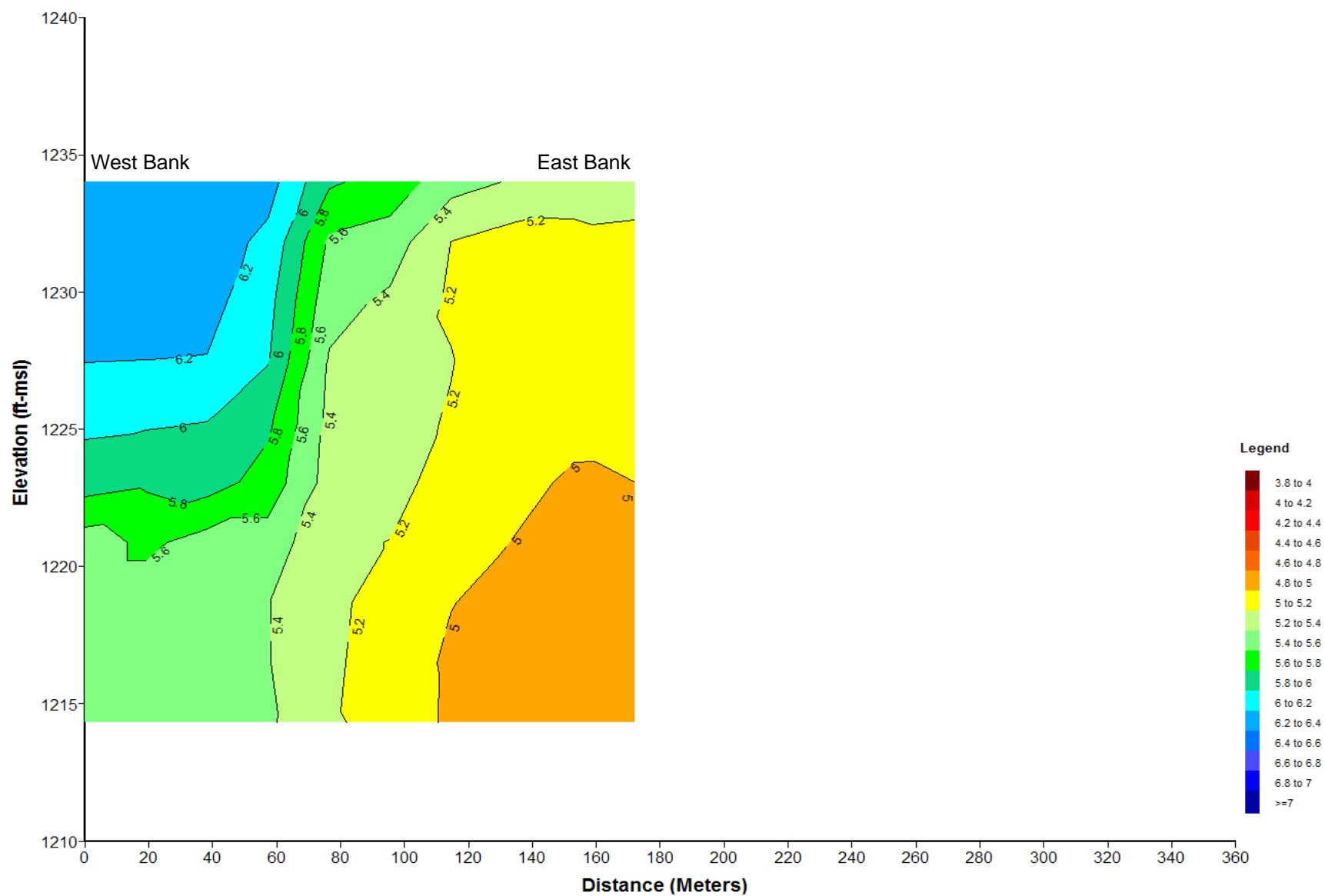


Figure 27. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 5, 2010.

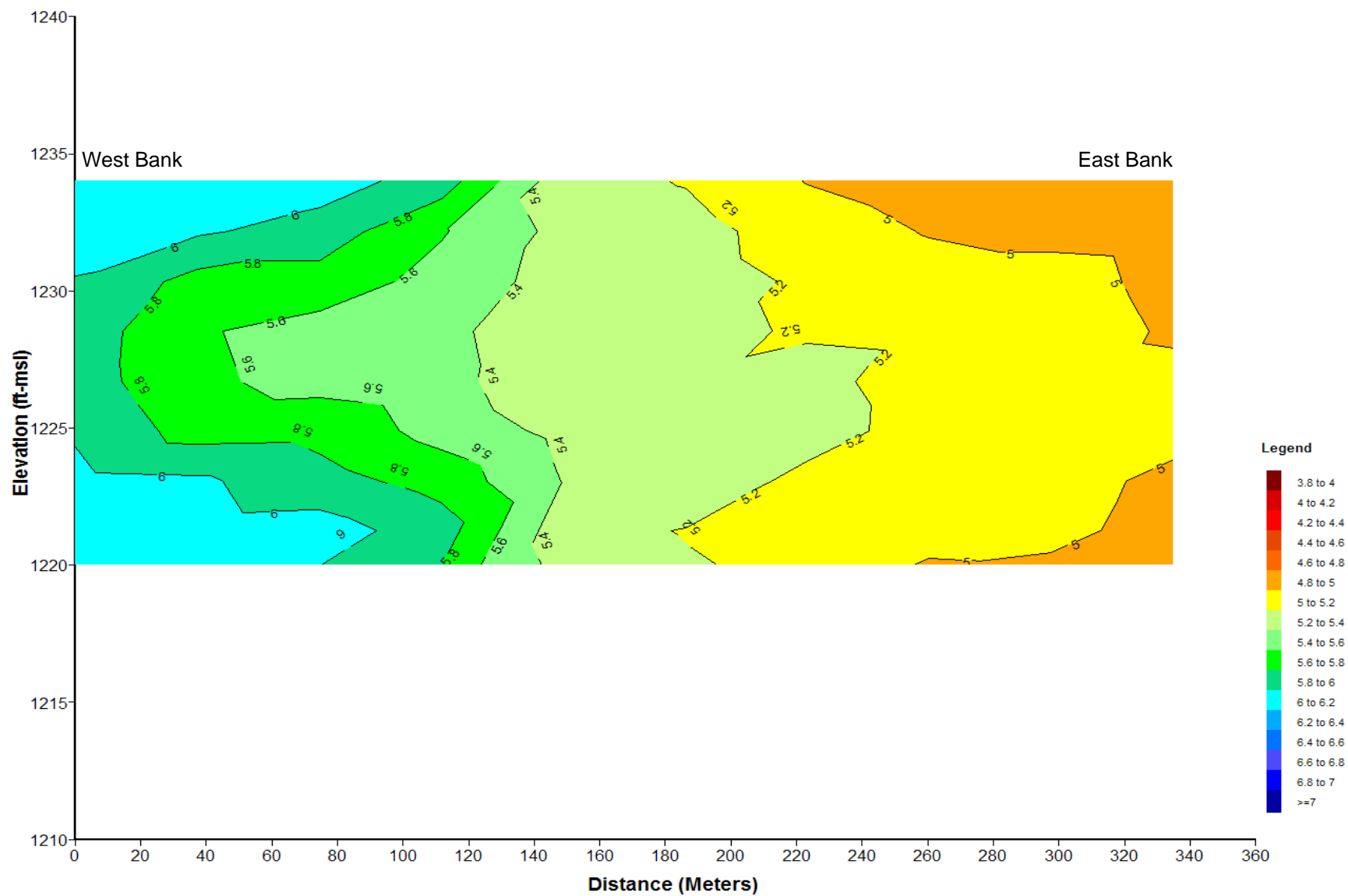


Figure 28. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 5, 2010.

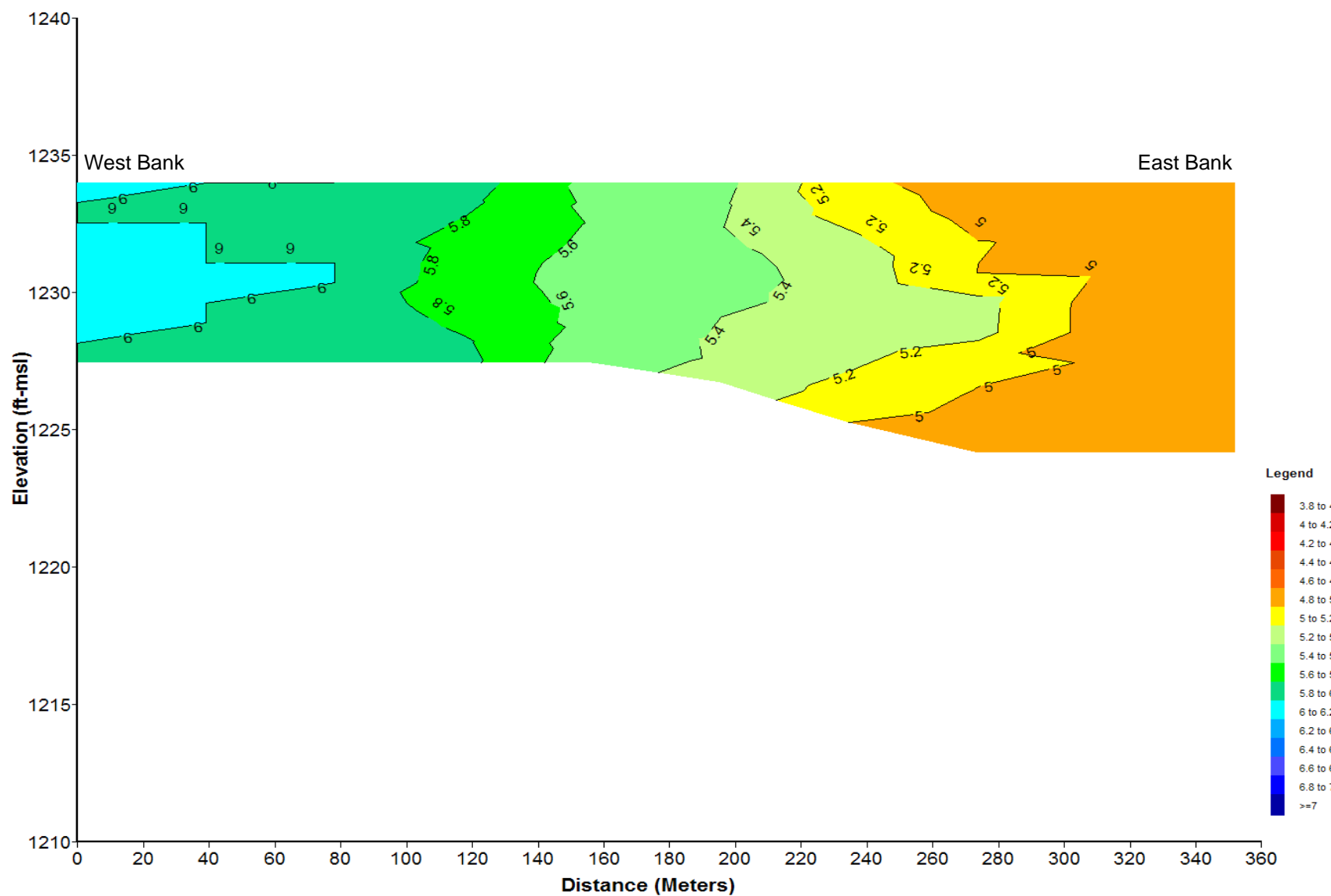


Figure 29. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 5, 2010.

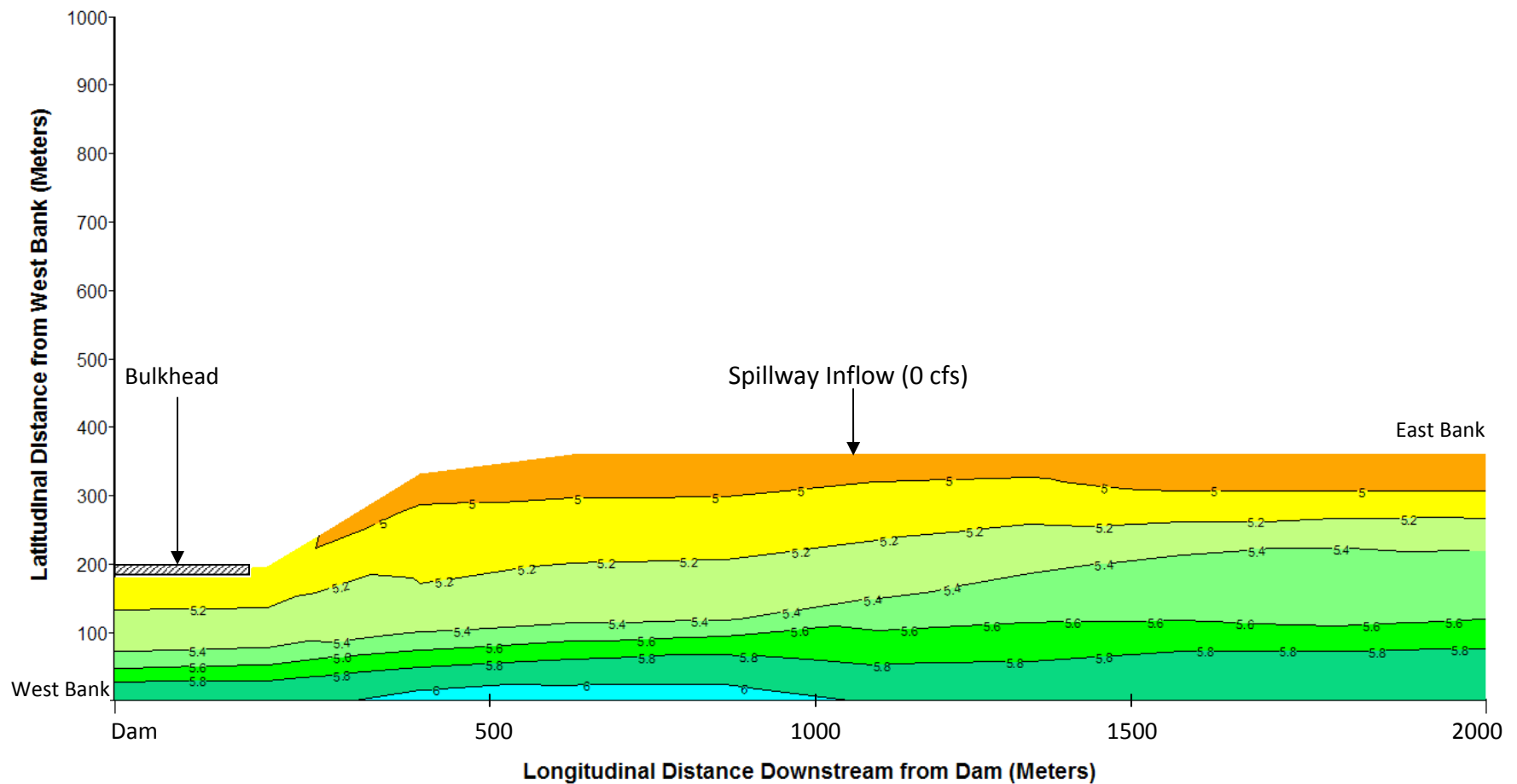


Figure 30. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 5, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

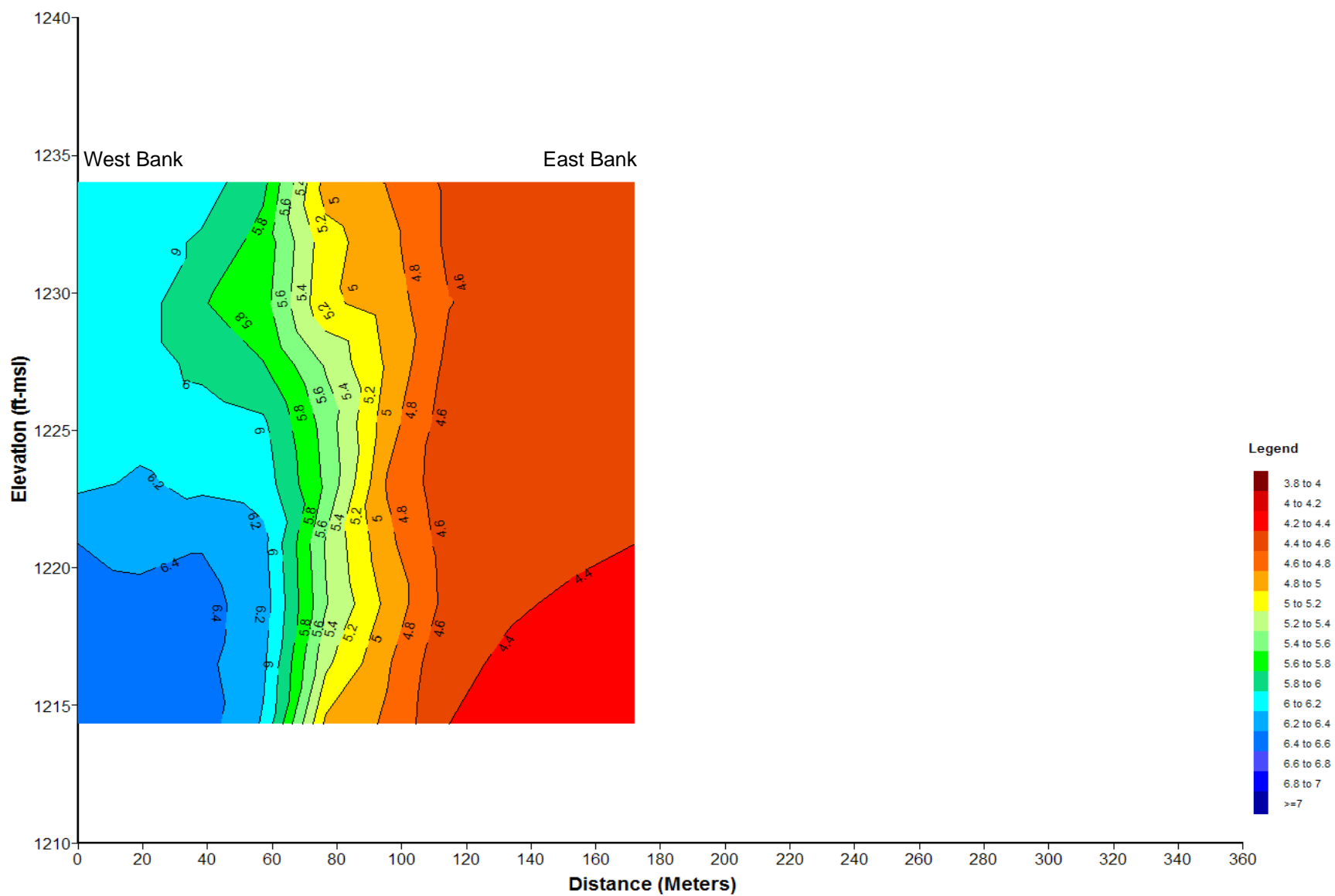


Figure 31. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 10, 2010.

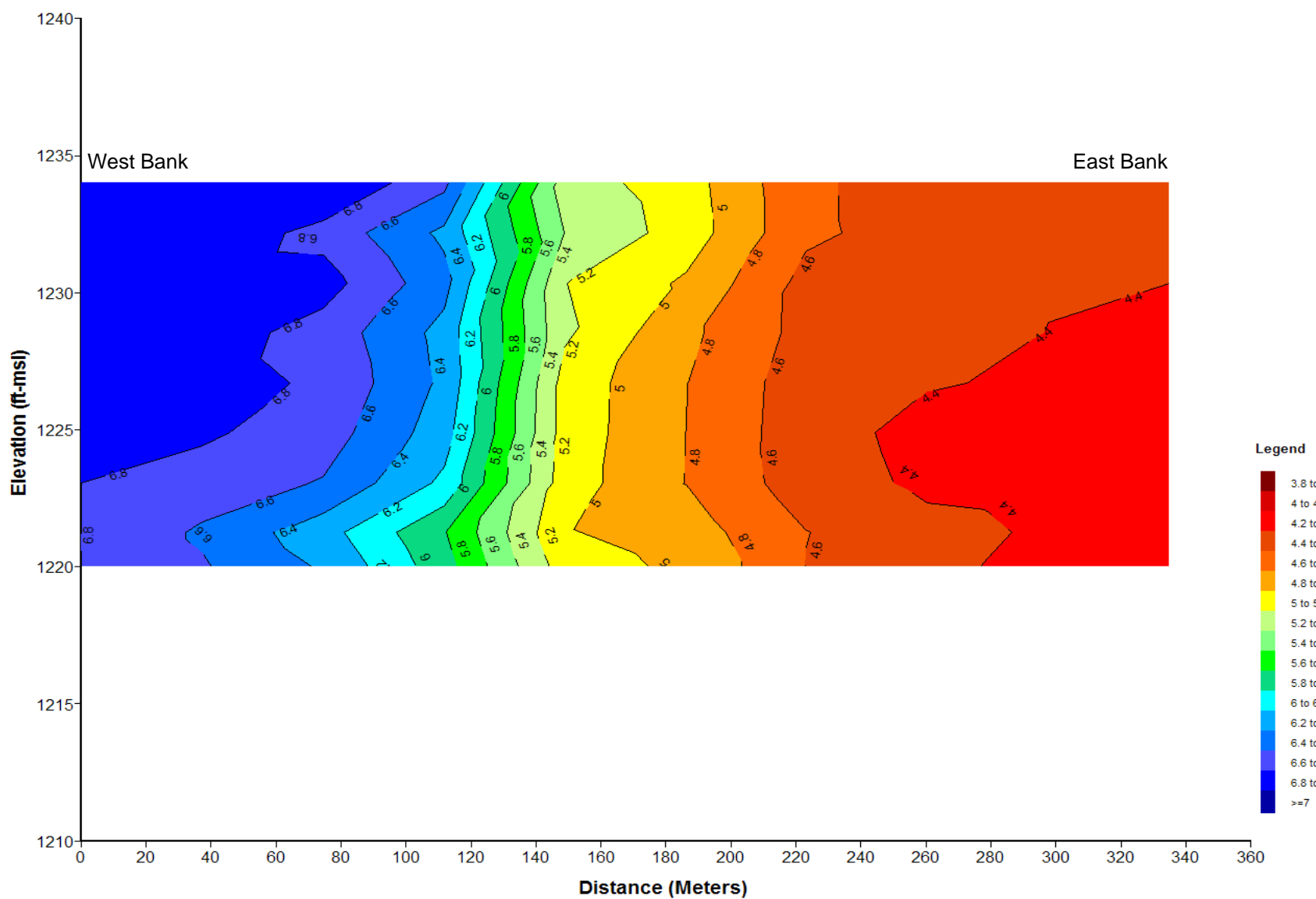


Figure 32. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 10, 2010.

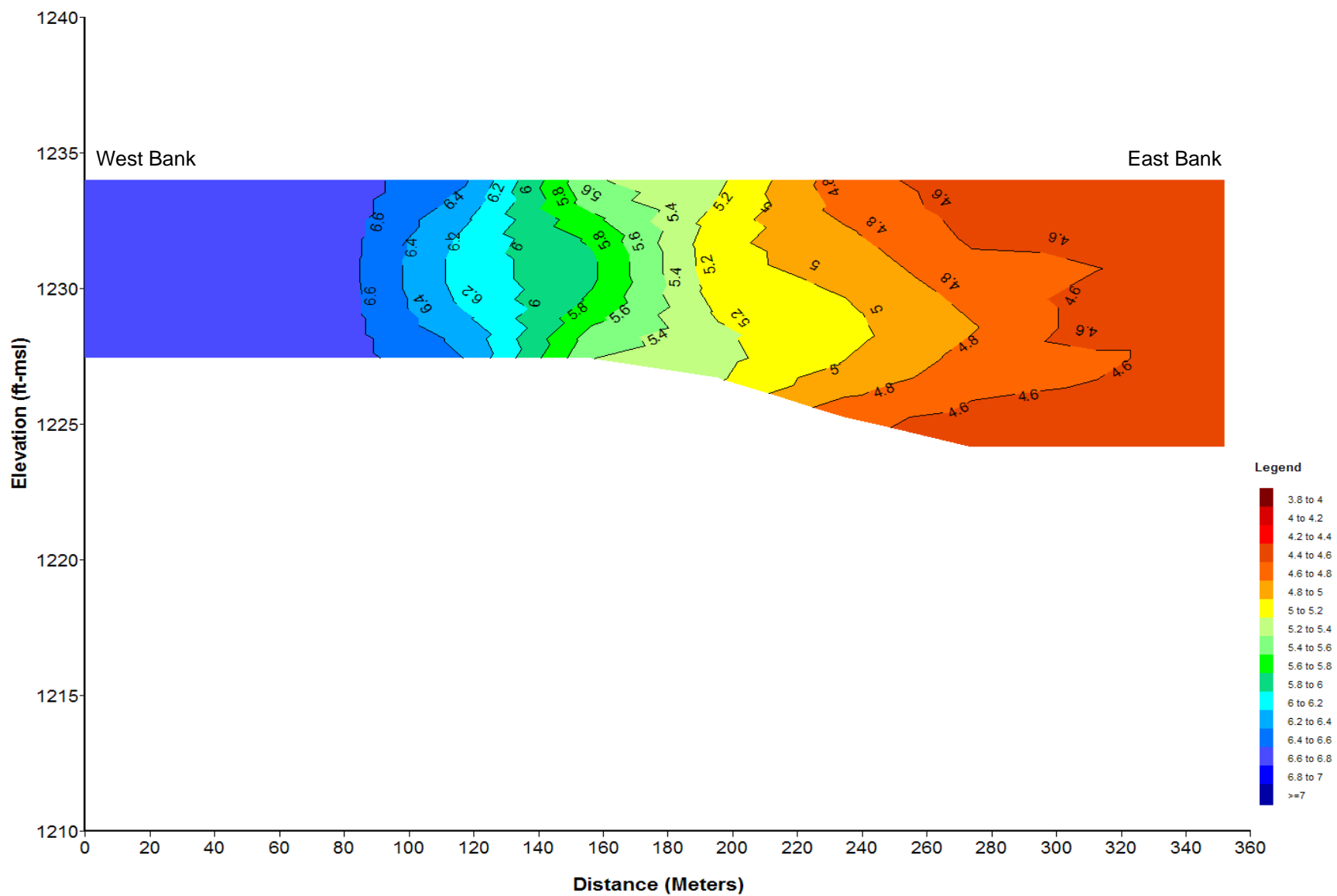


Figure 33. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 10, 2010.

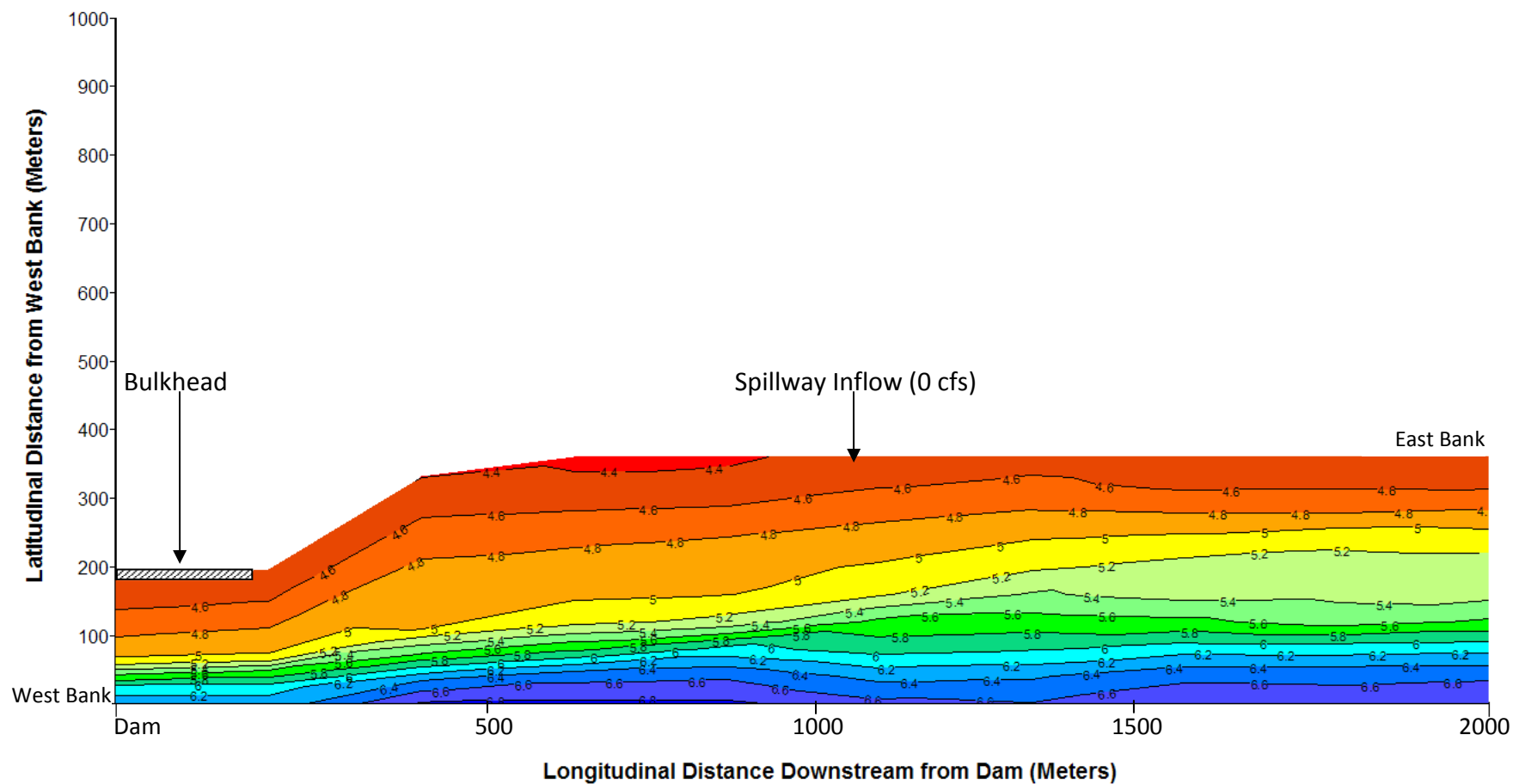


Figure 34. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 10, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

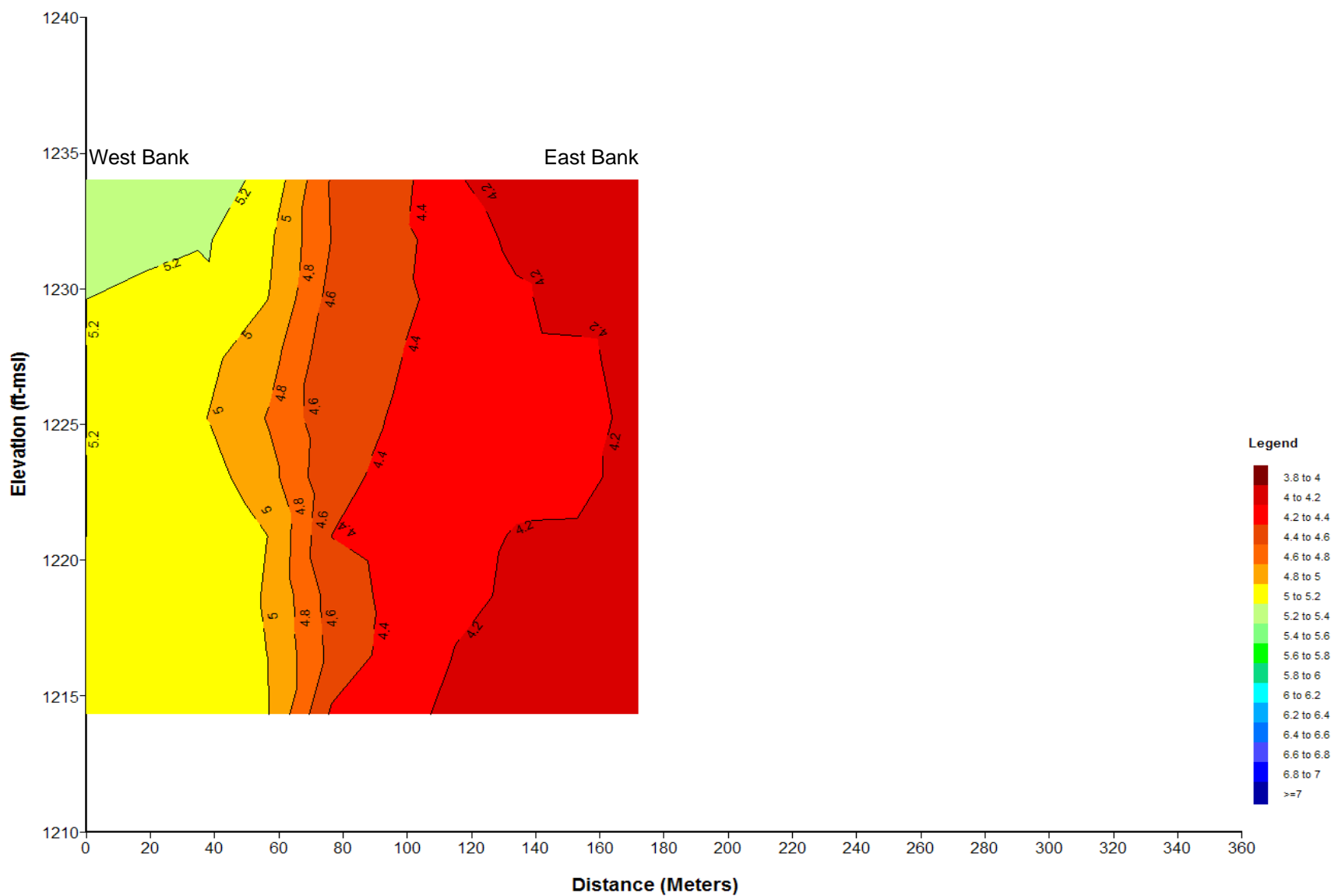


Figure 35. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 12, 2010.

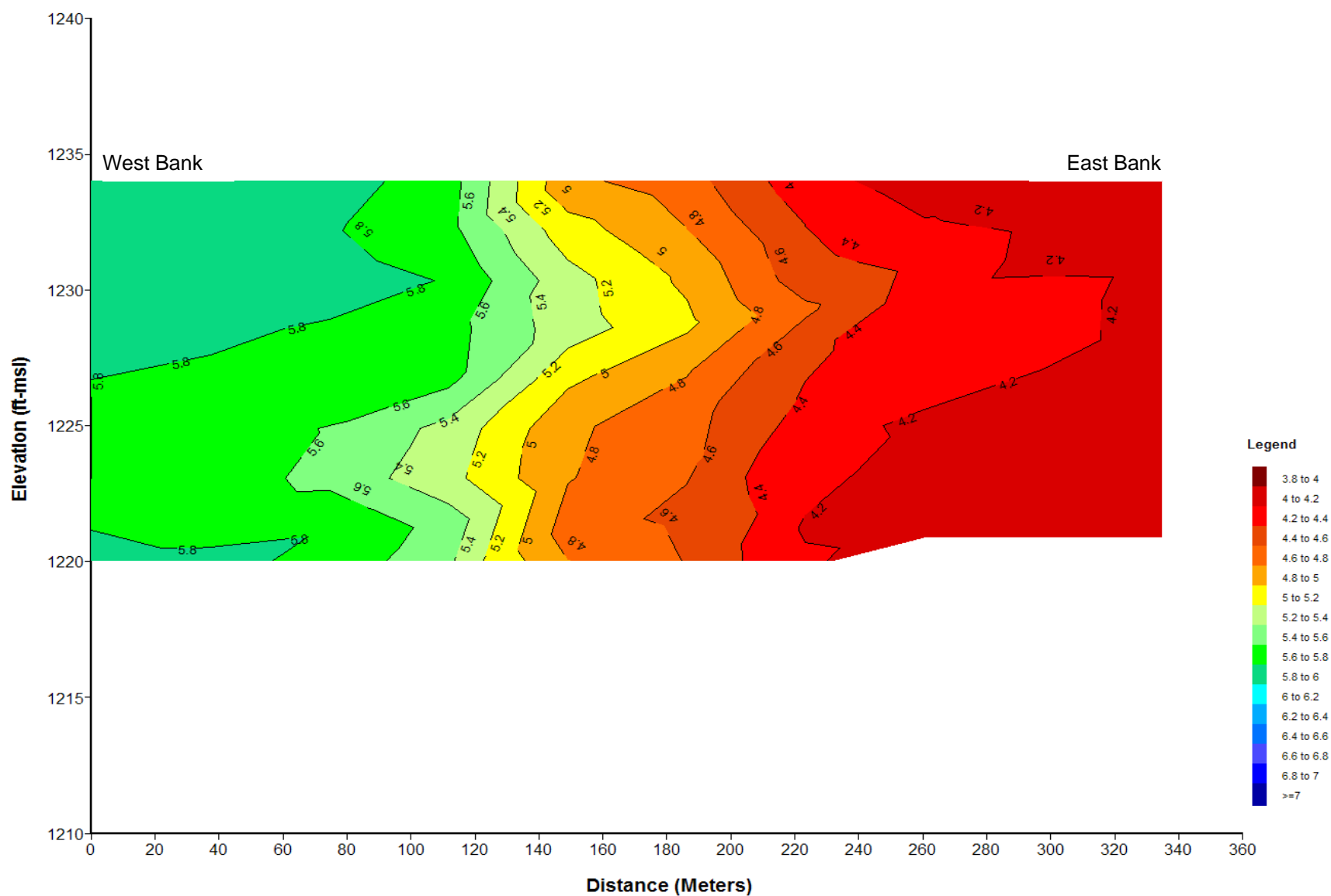


Figure 36. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 12, 2010.

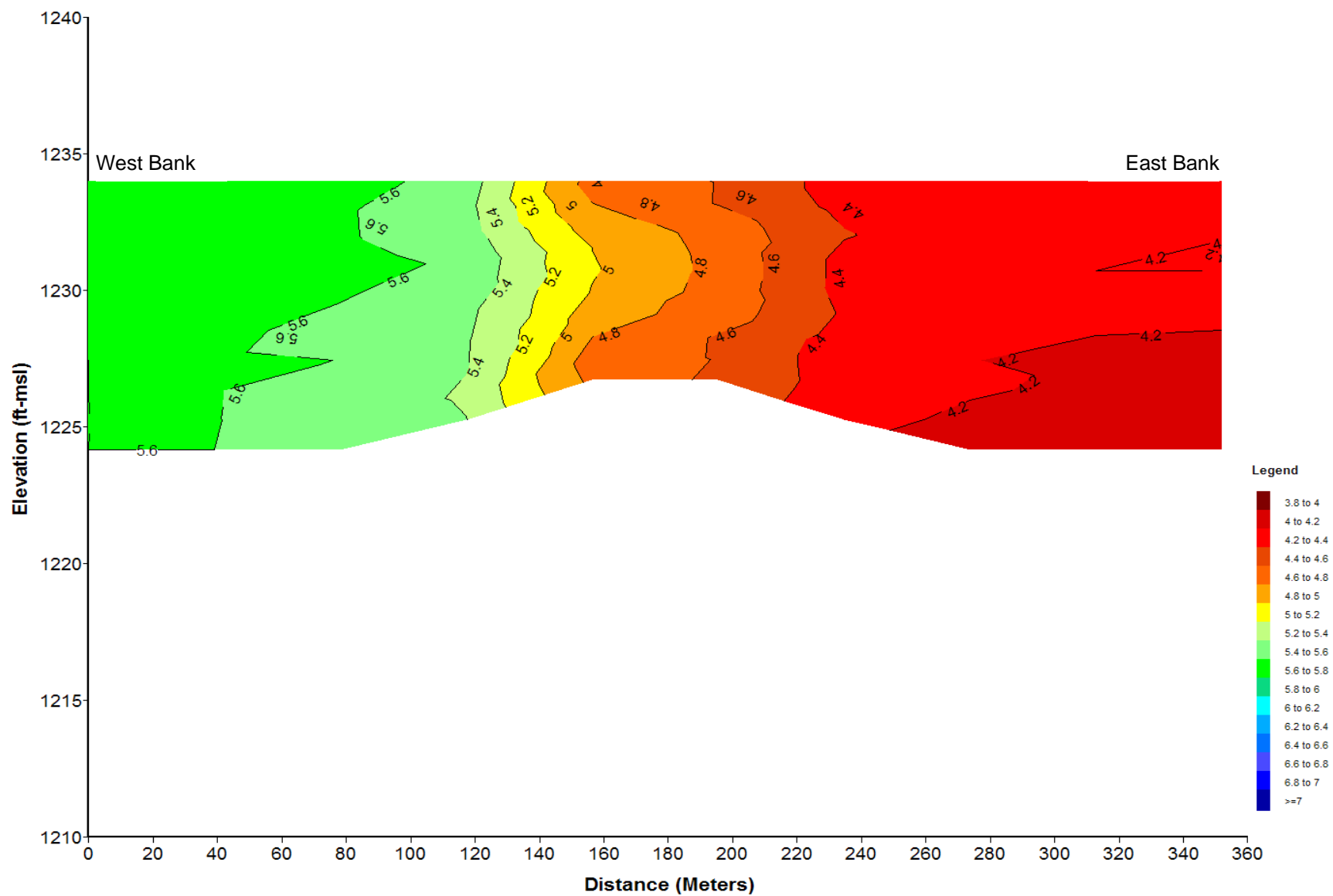


Figure 37. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 12, 2010.

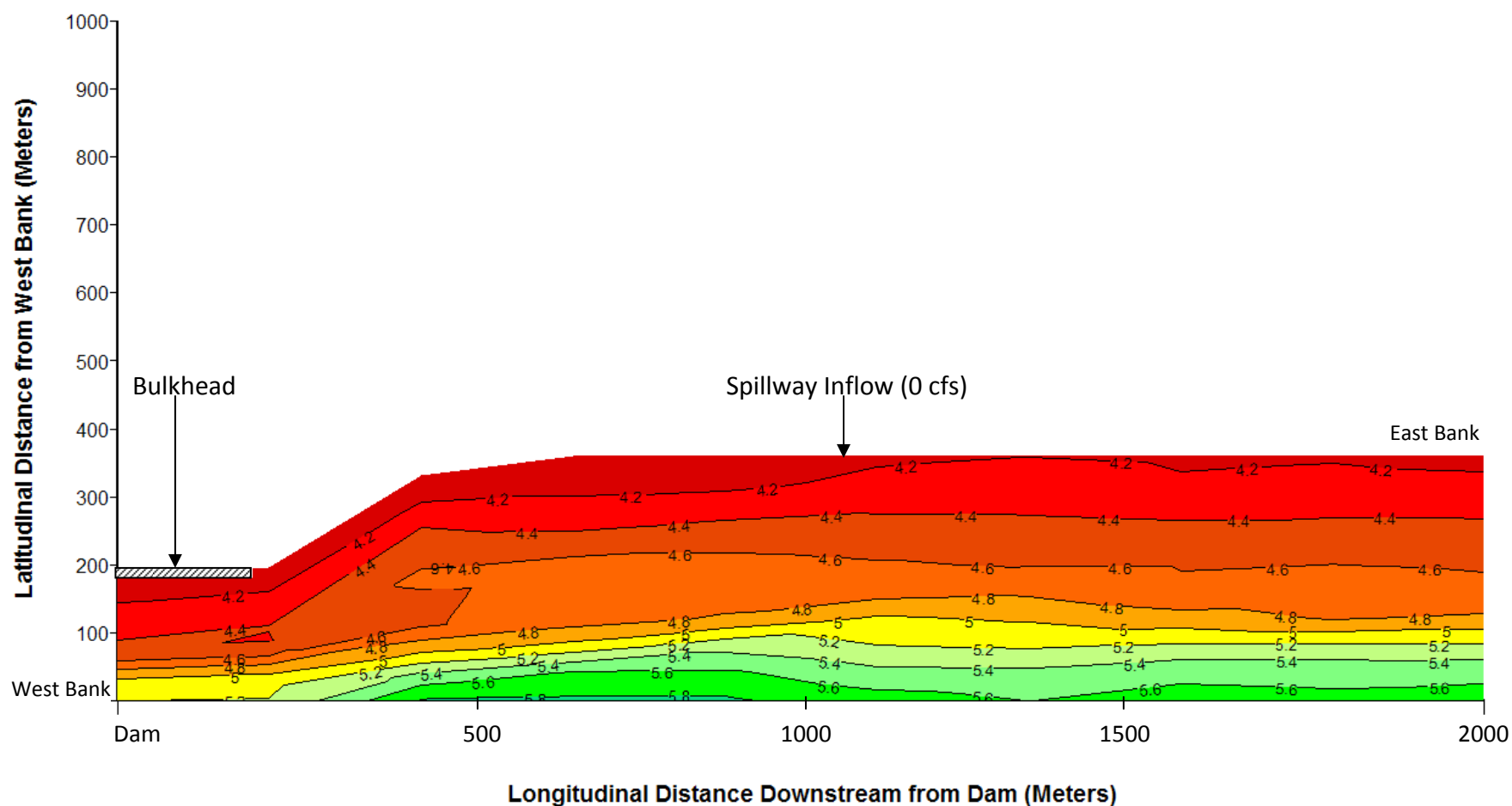


Figure 38. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 12, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

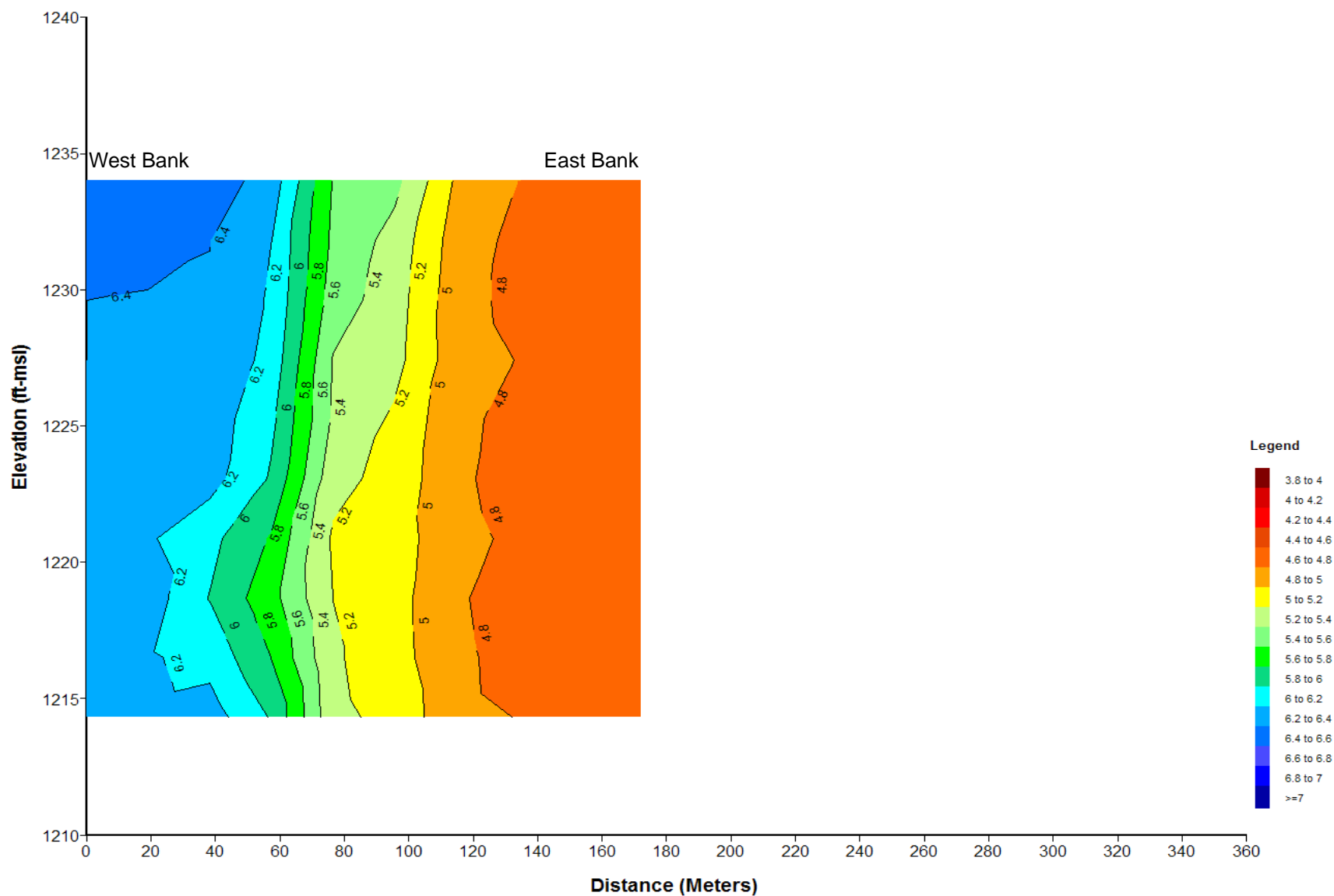


Figure 39. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 17, 2010.

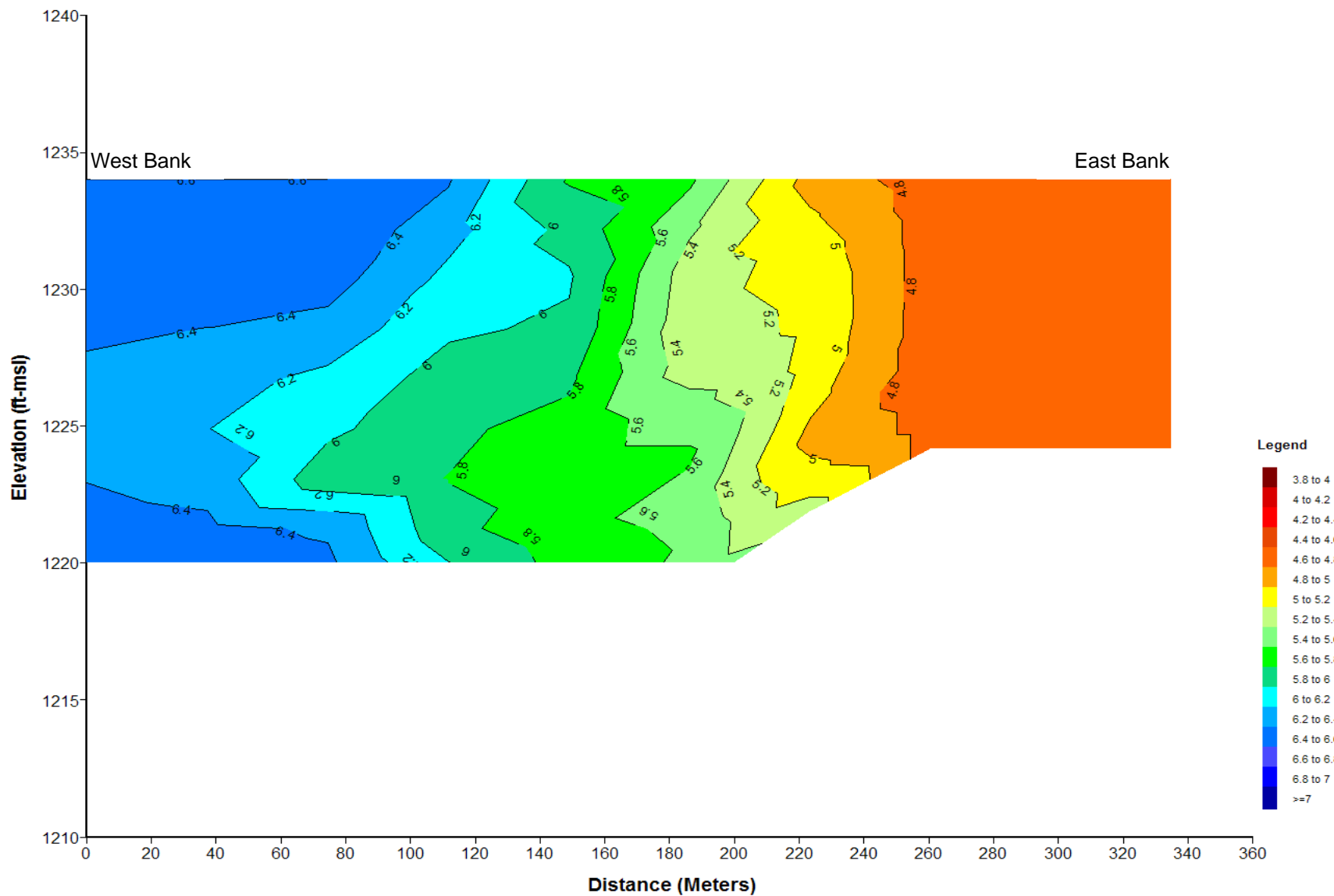


Figure 40. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 17, 2010.

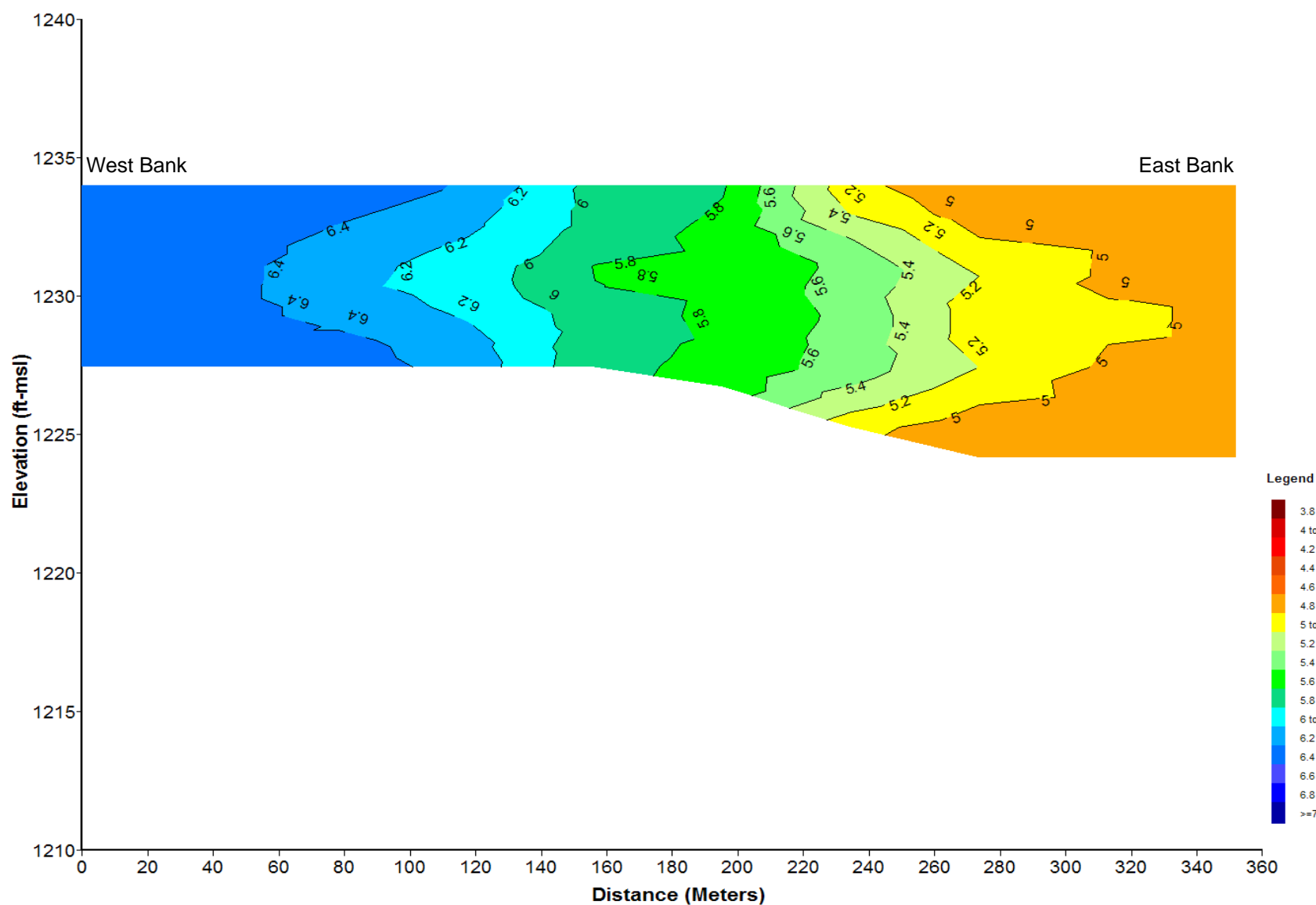


Figure 41. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 17, 2010.

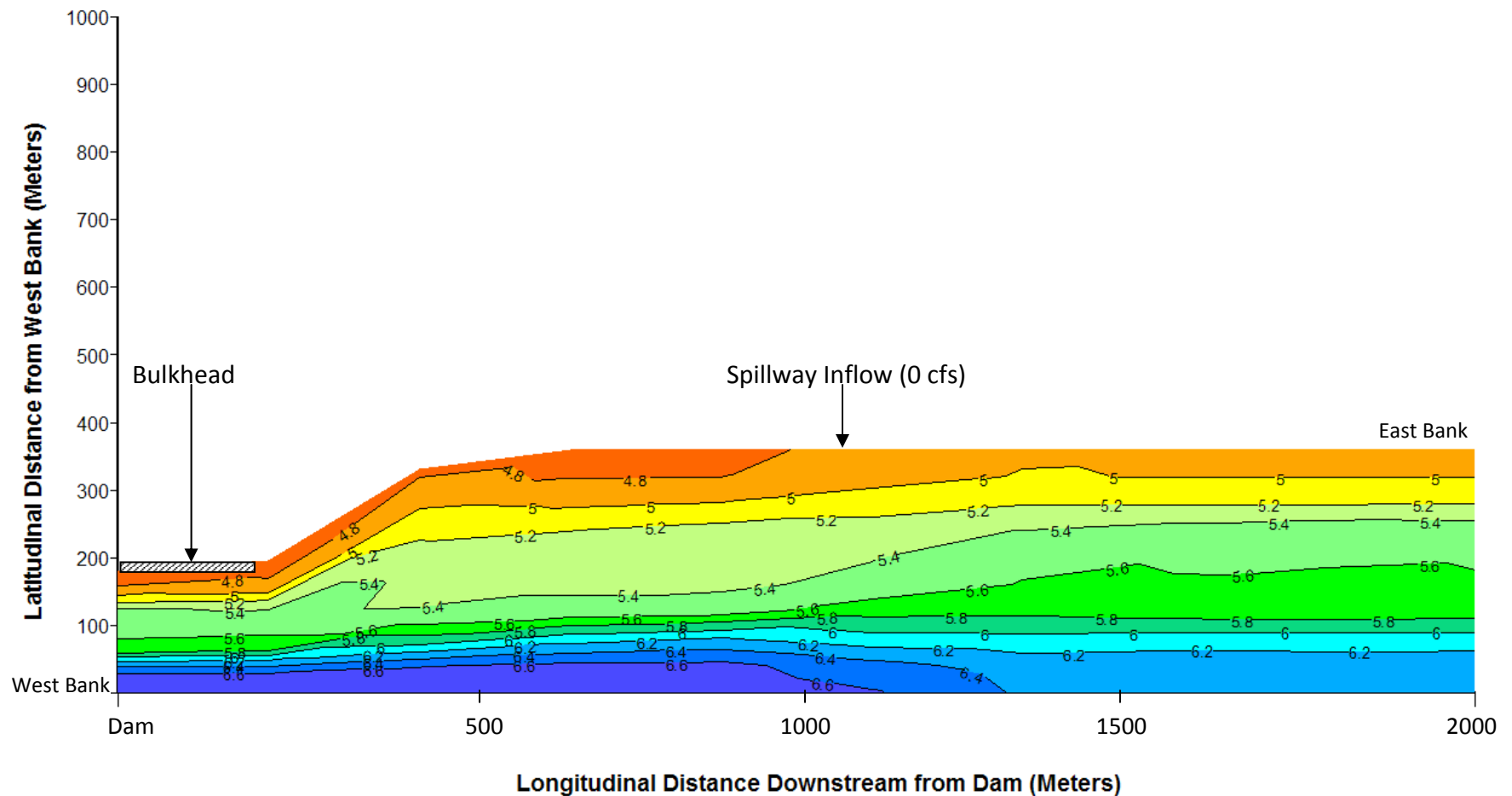


Figure 42. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 17, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

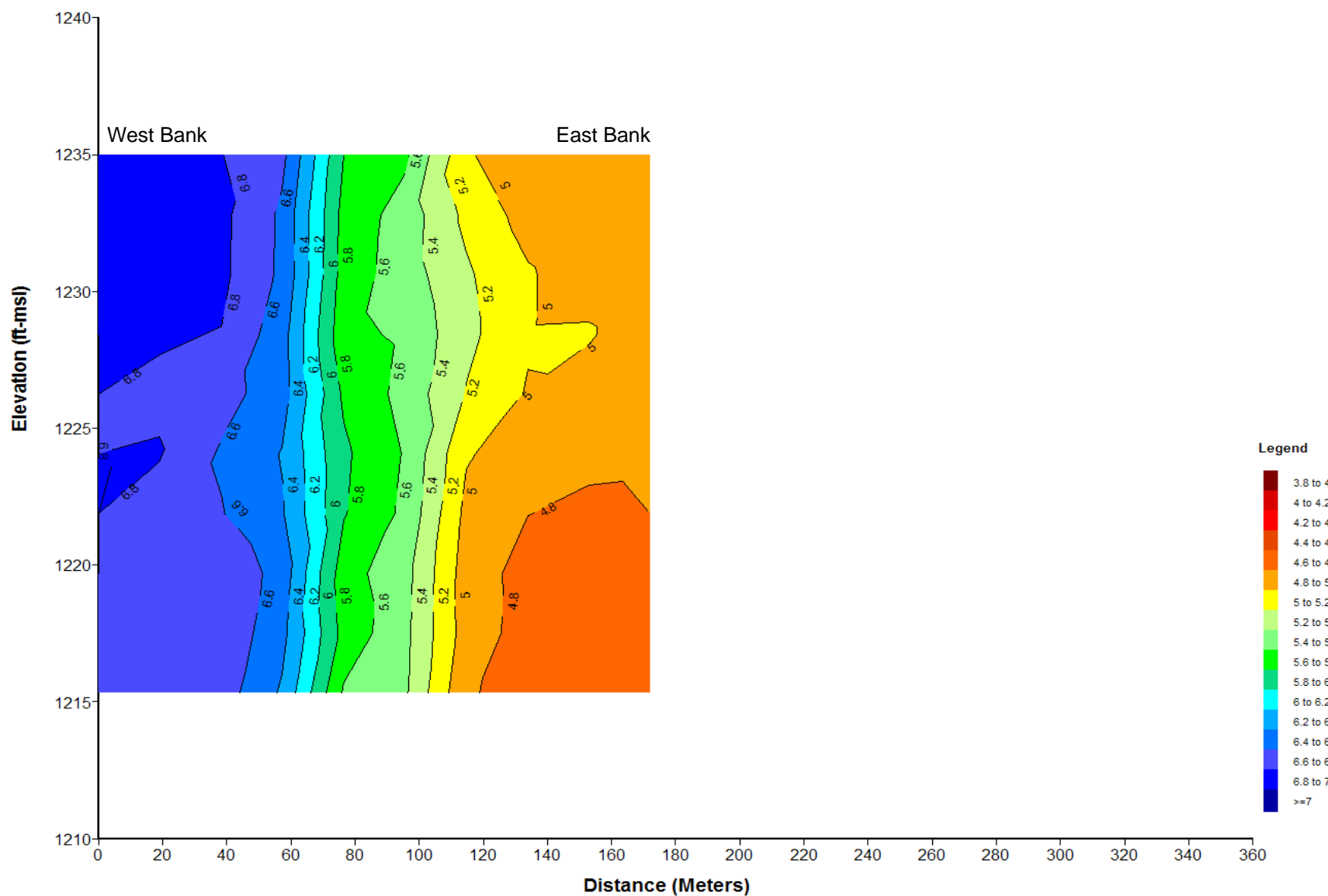


Figure 43. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 19, 2010.

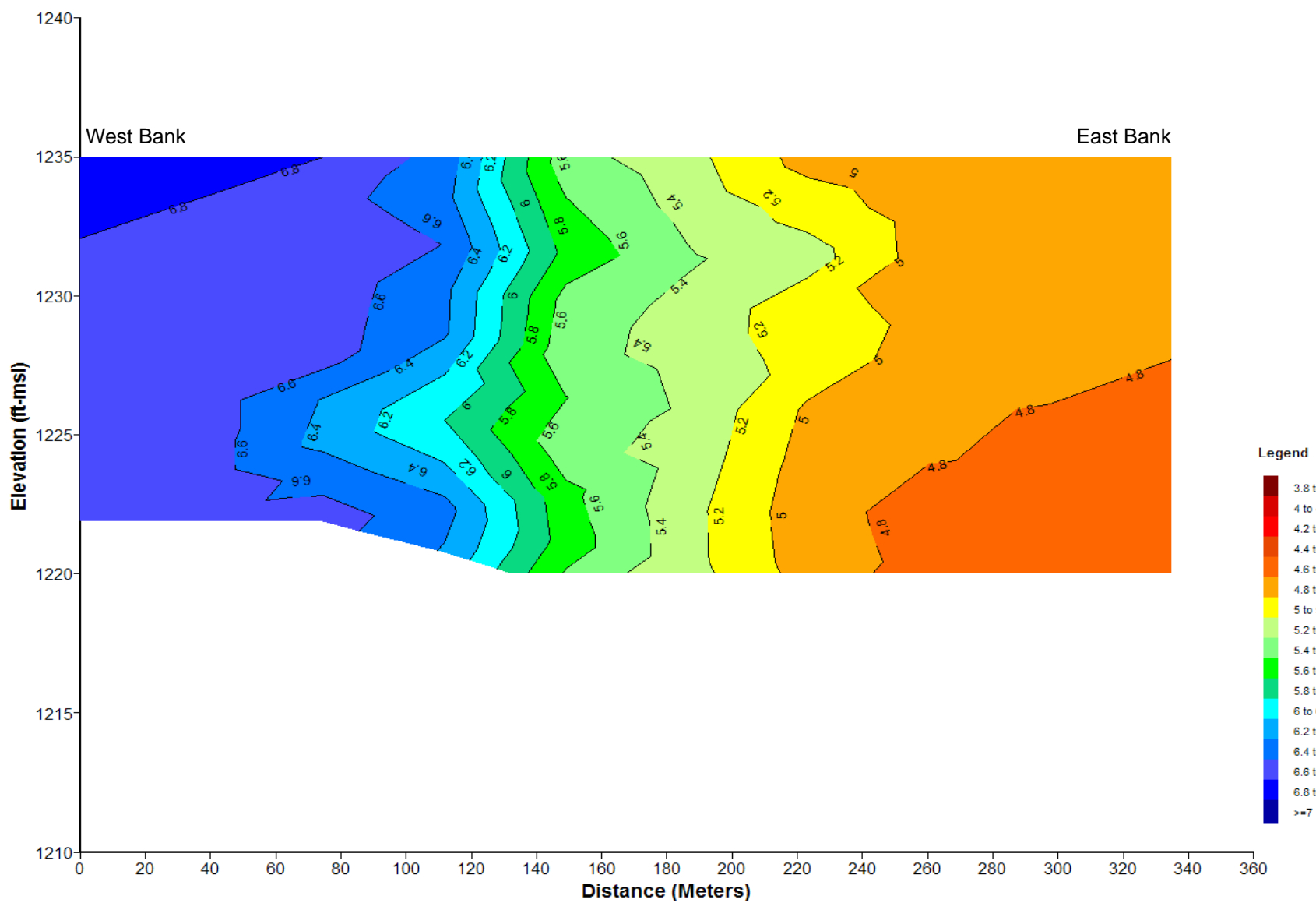


Figure 44. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 19, 2010.

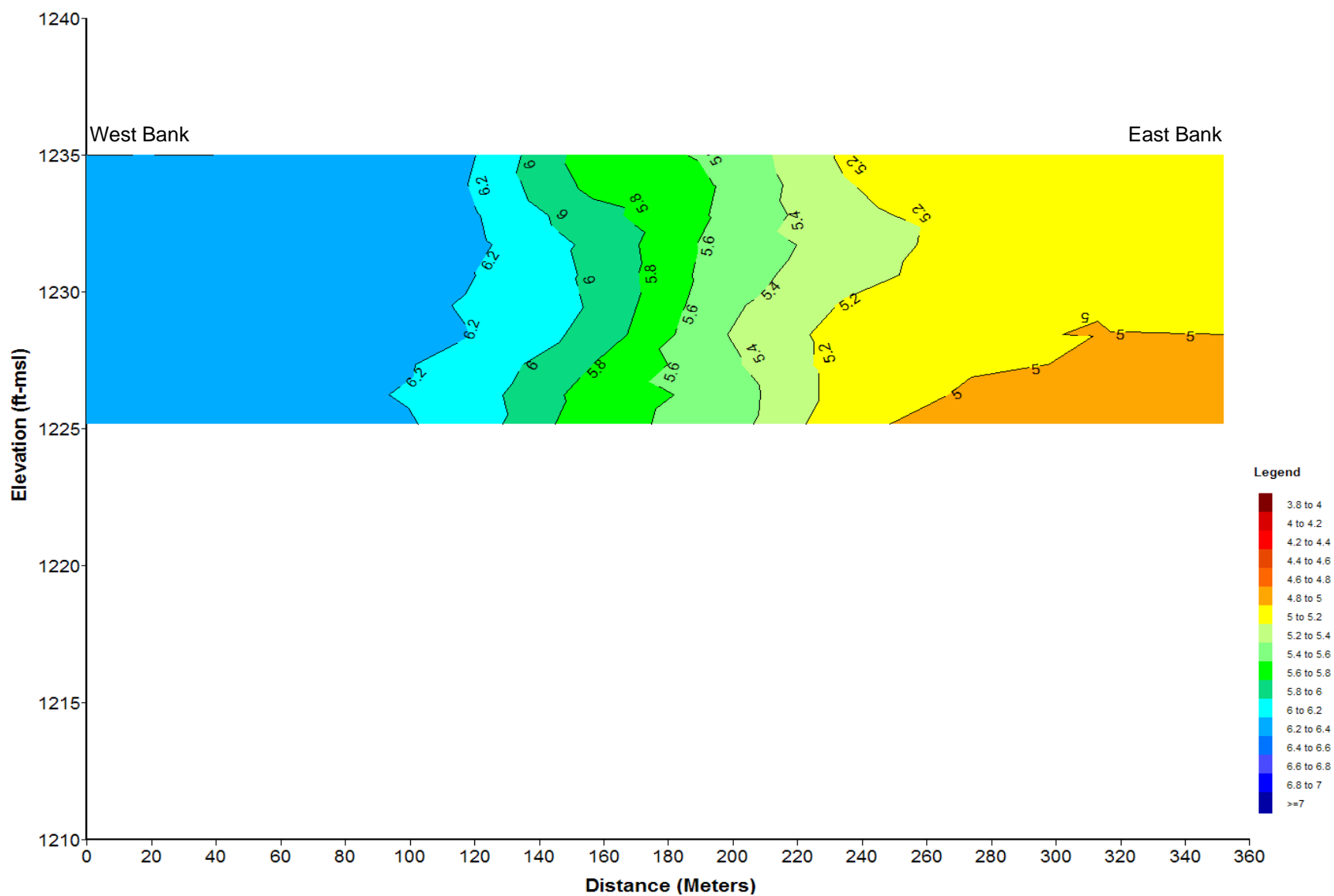


Figure 45. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 19, 2010.

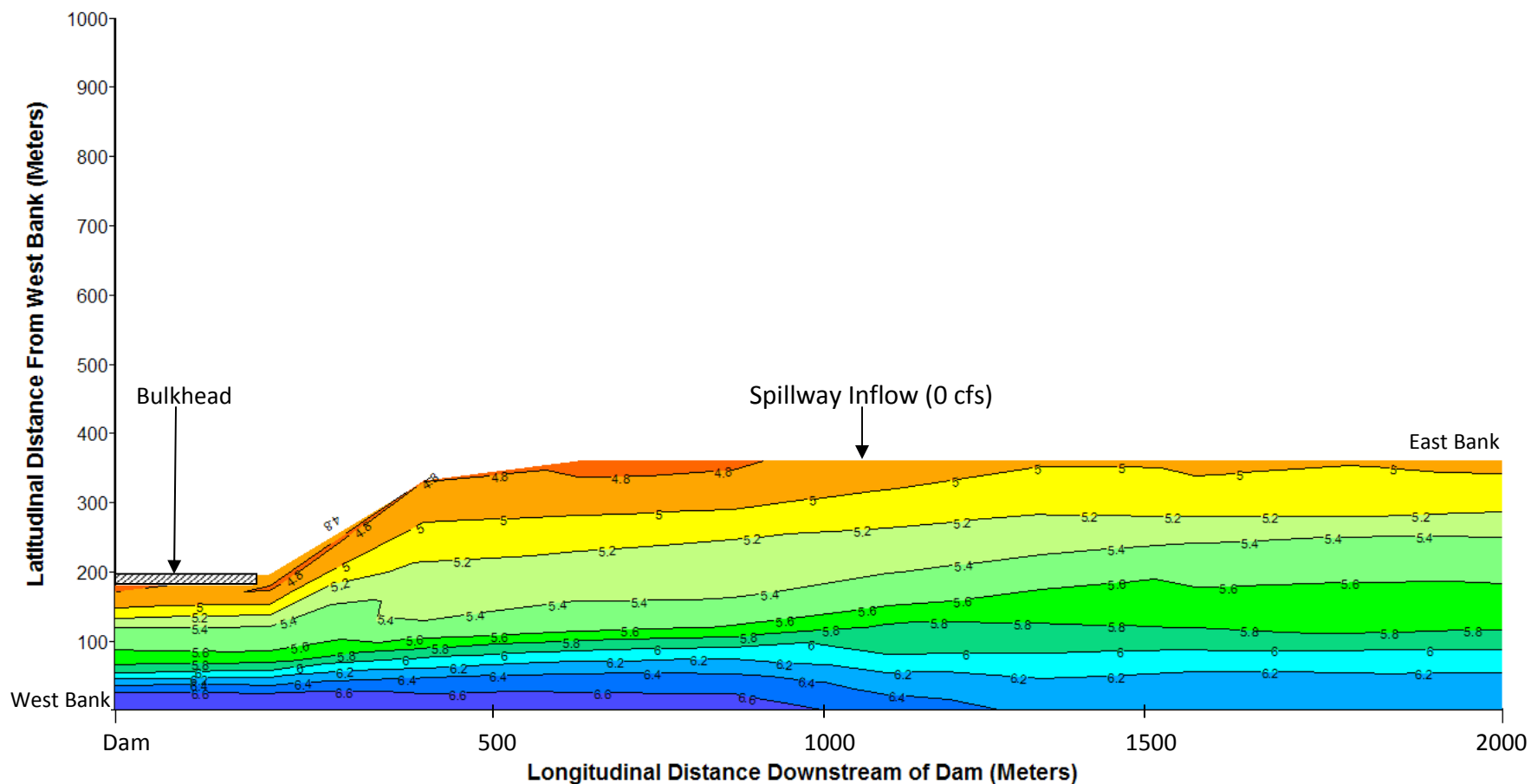


Figure 46. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 19, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

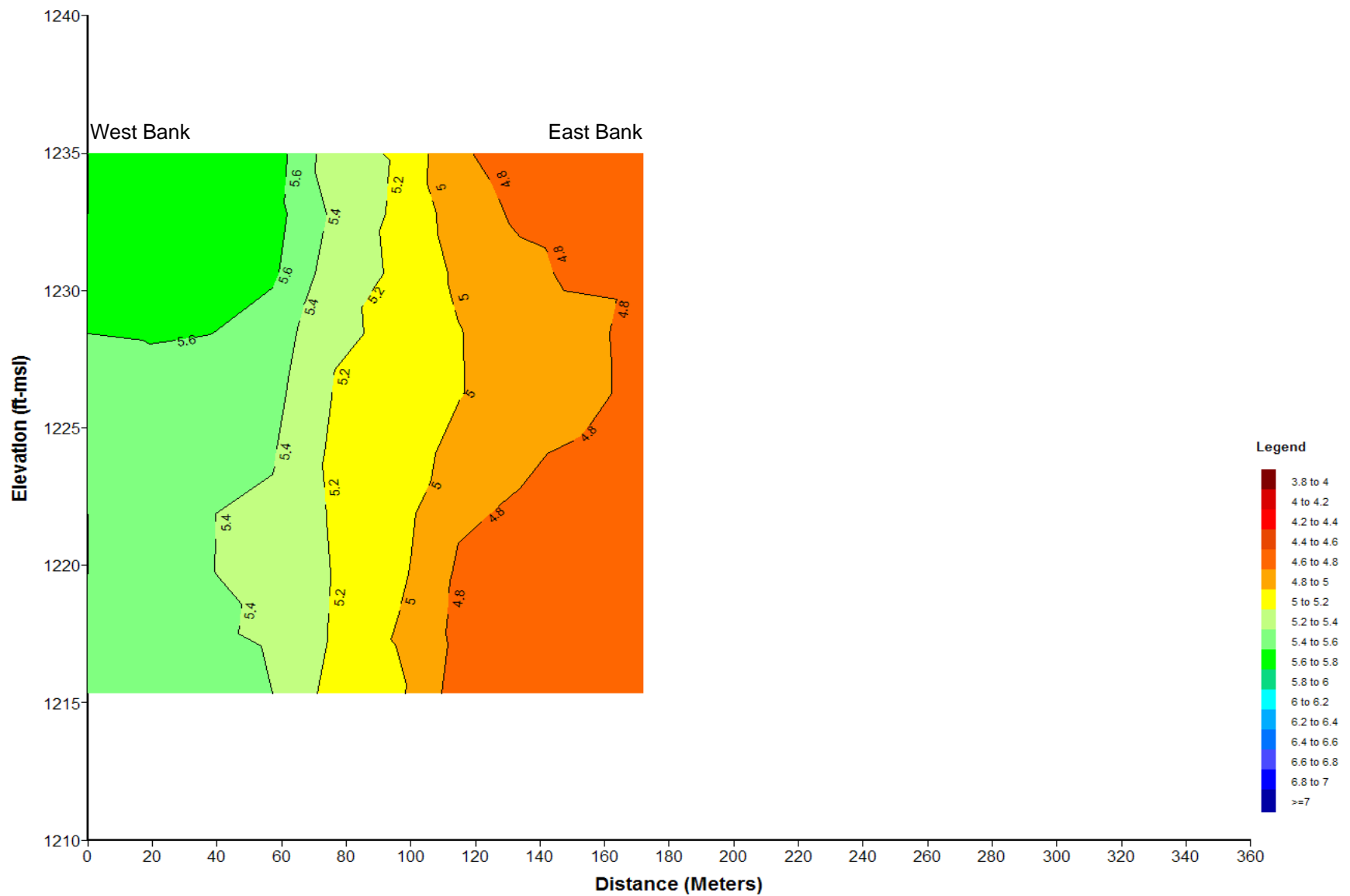


Figure 47. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 24, 2010.

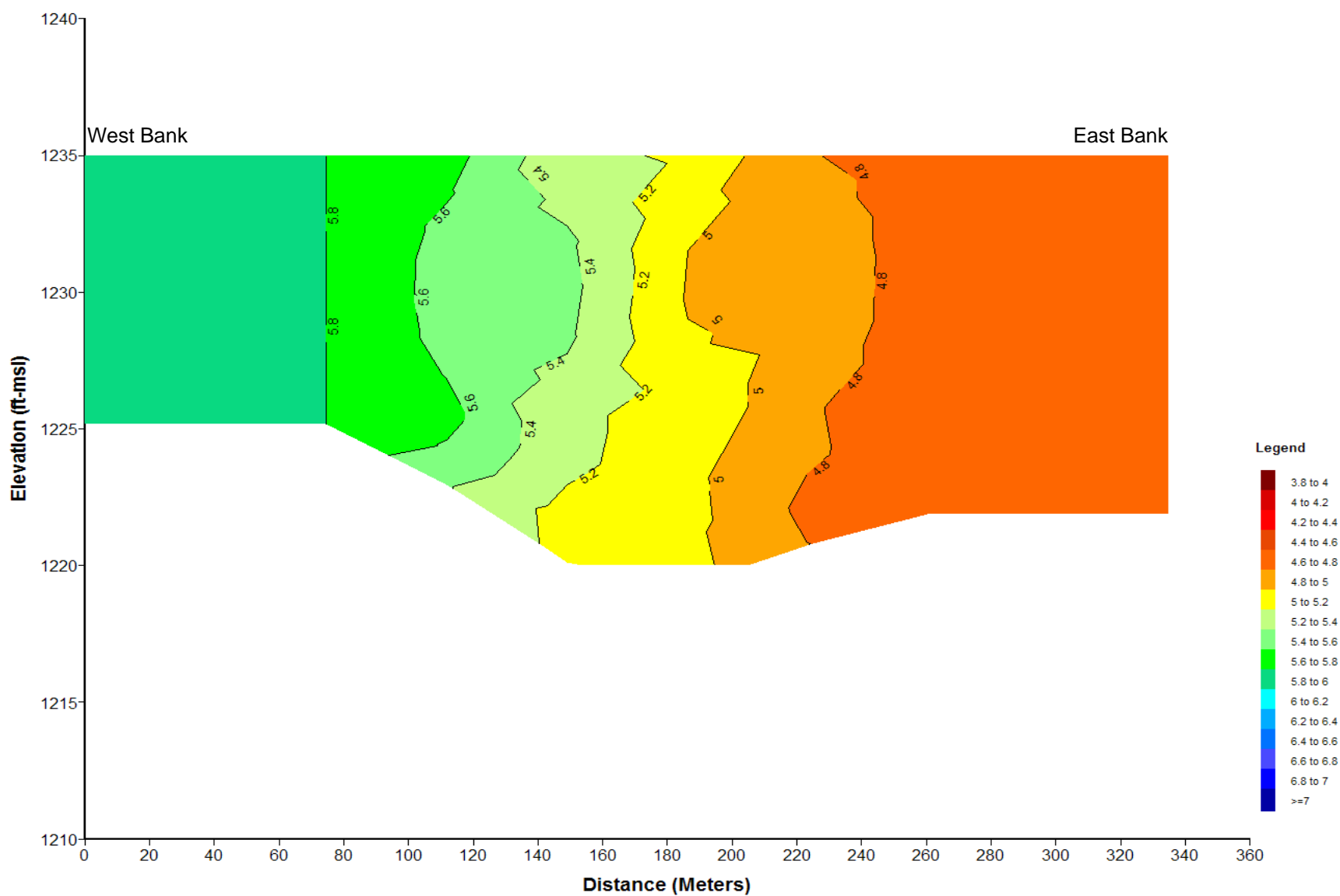


Figure 48. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 24, 2010.

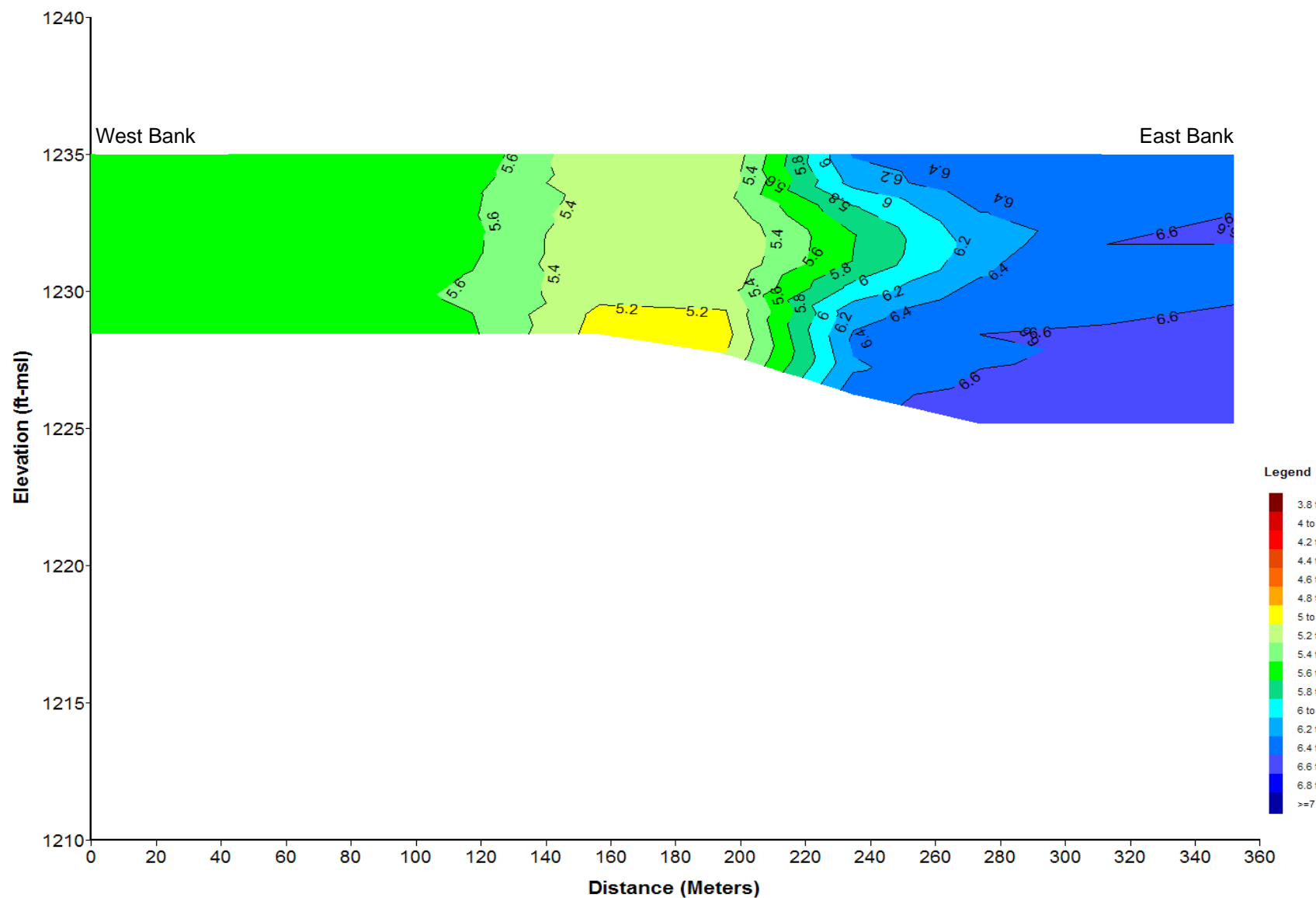


Figure 49. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 24, 2010.

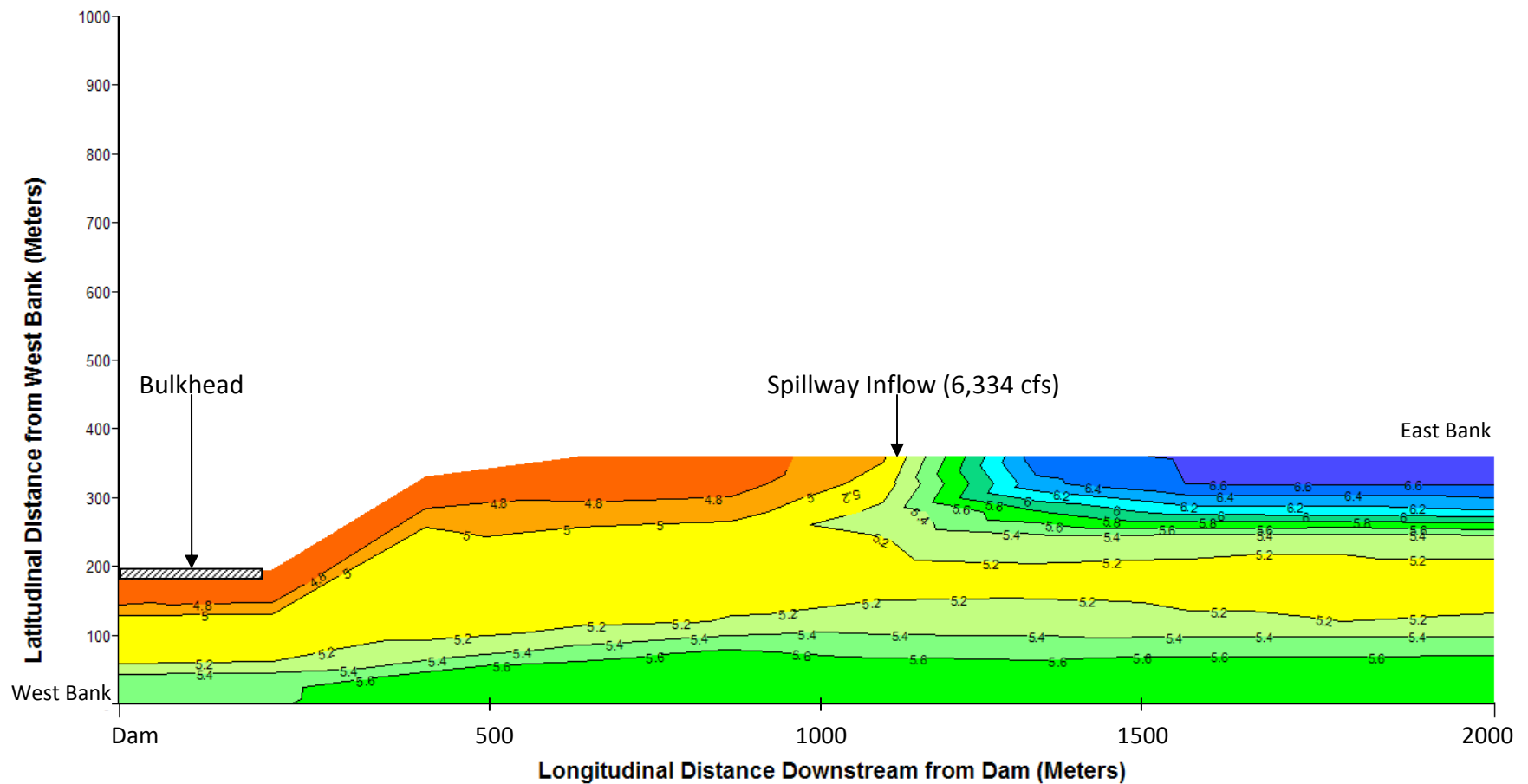


Figure 50. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 24, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).

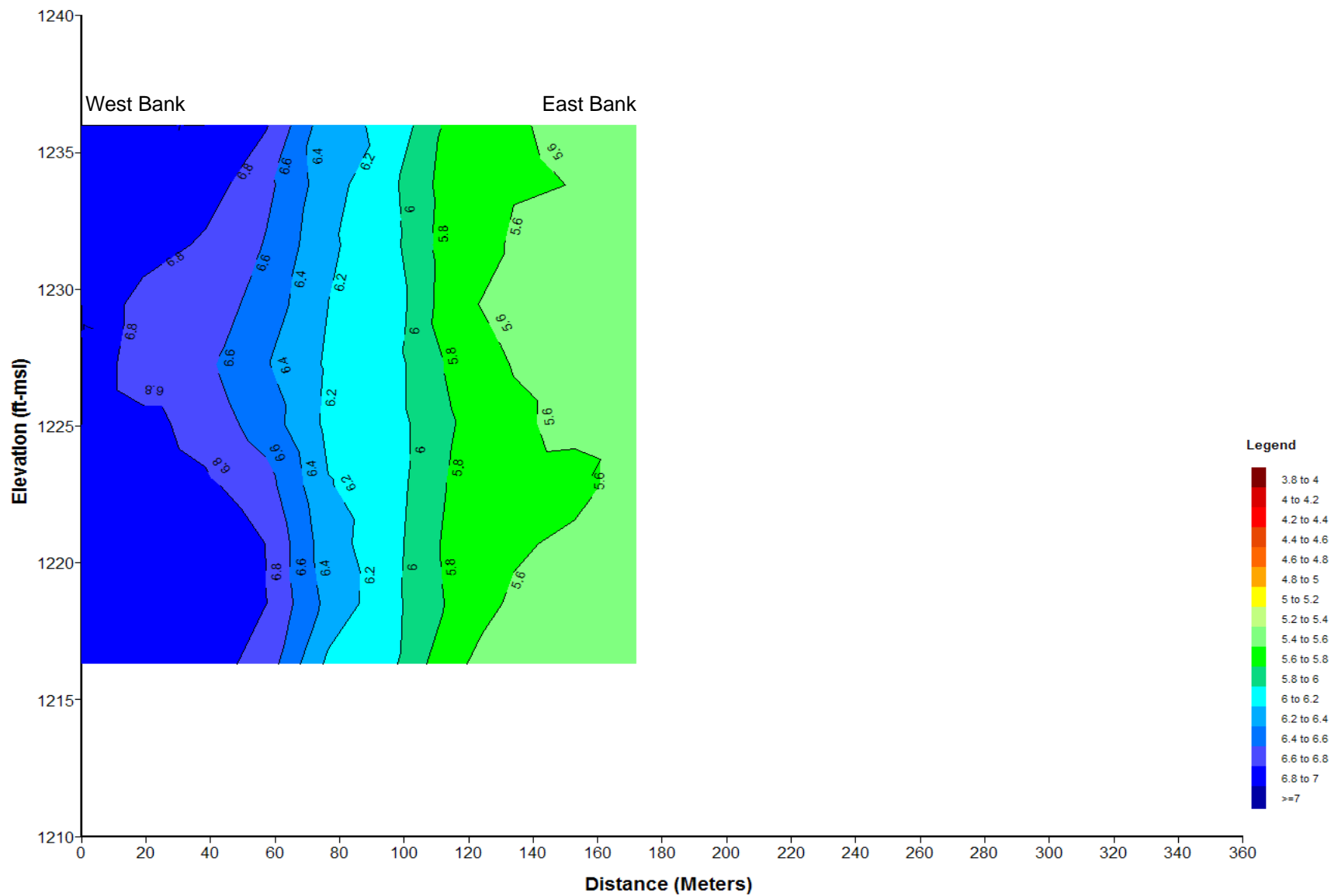


Figure 51. Contour plot depicting dissolved oxygen concentrations measured across the near-dam transect (FTRTW3) on August 26, 2010.

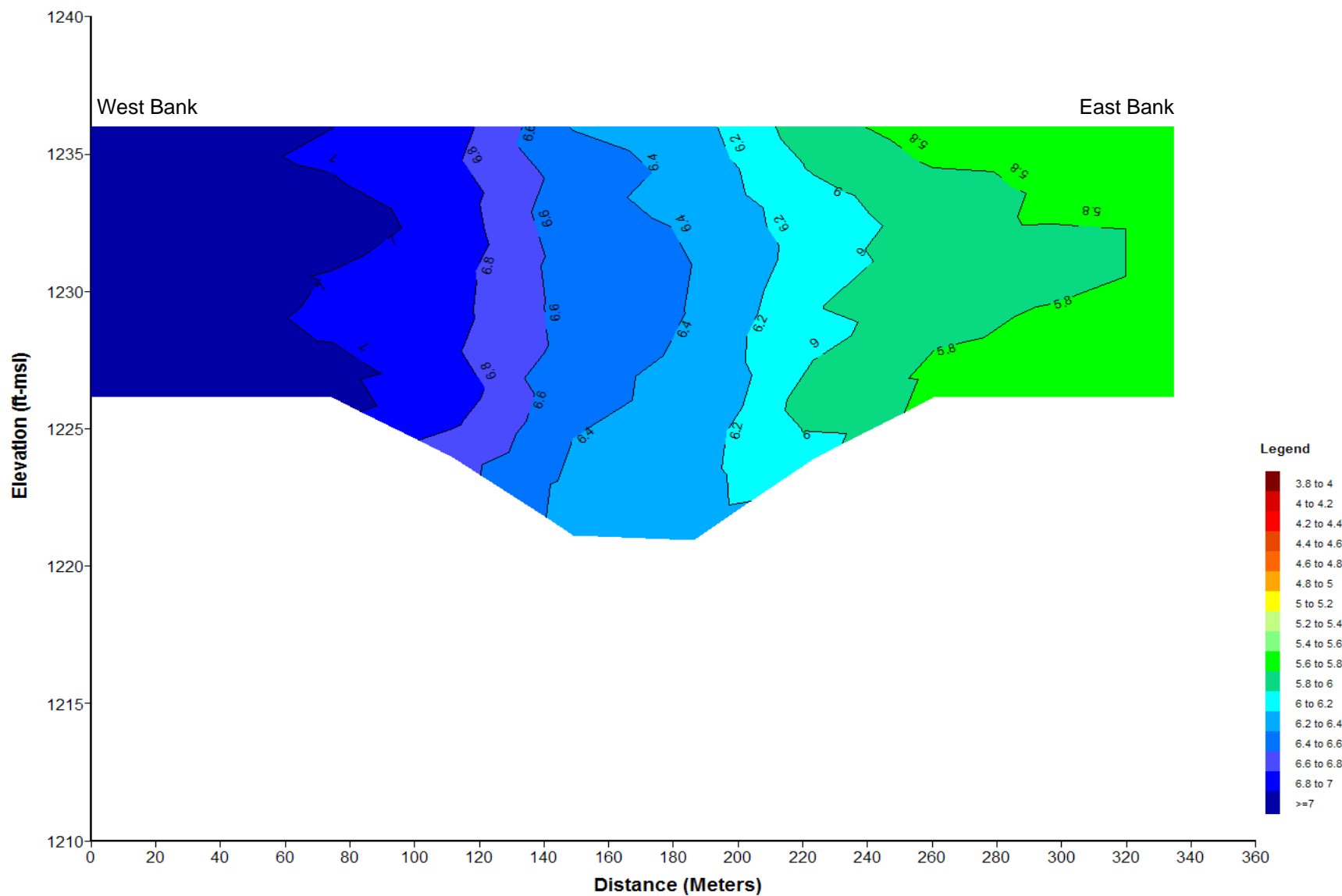


Figure 52. Contour plot depicting dissolved oxygen concentrations measured across the spillway transect (FTRTW2) on August 26, 2010.

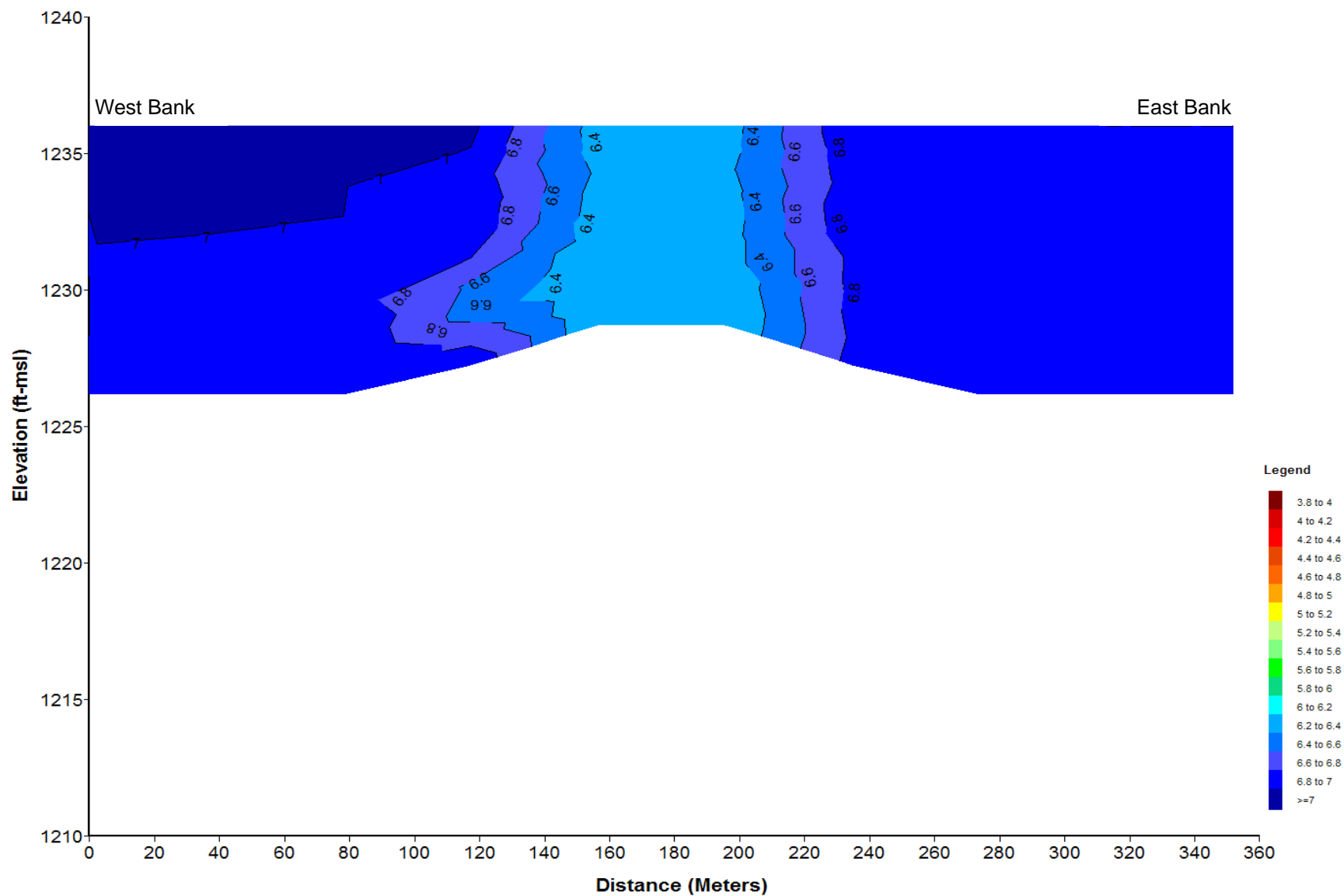


Figure 53. Contour plot depicting dissolved oxygen concentrations measured across the downstream transect (FTRTW1) on August 26, 2010.

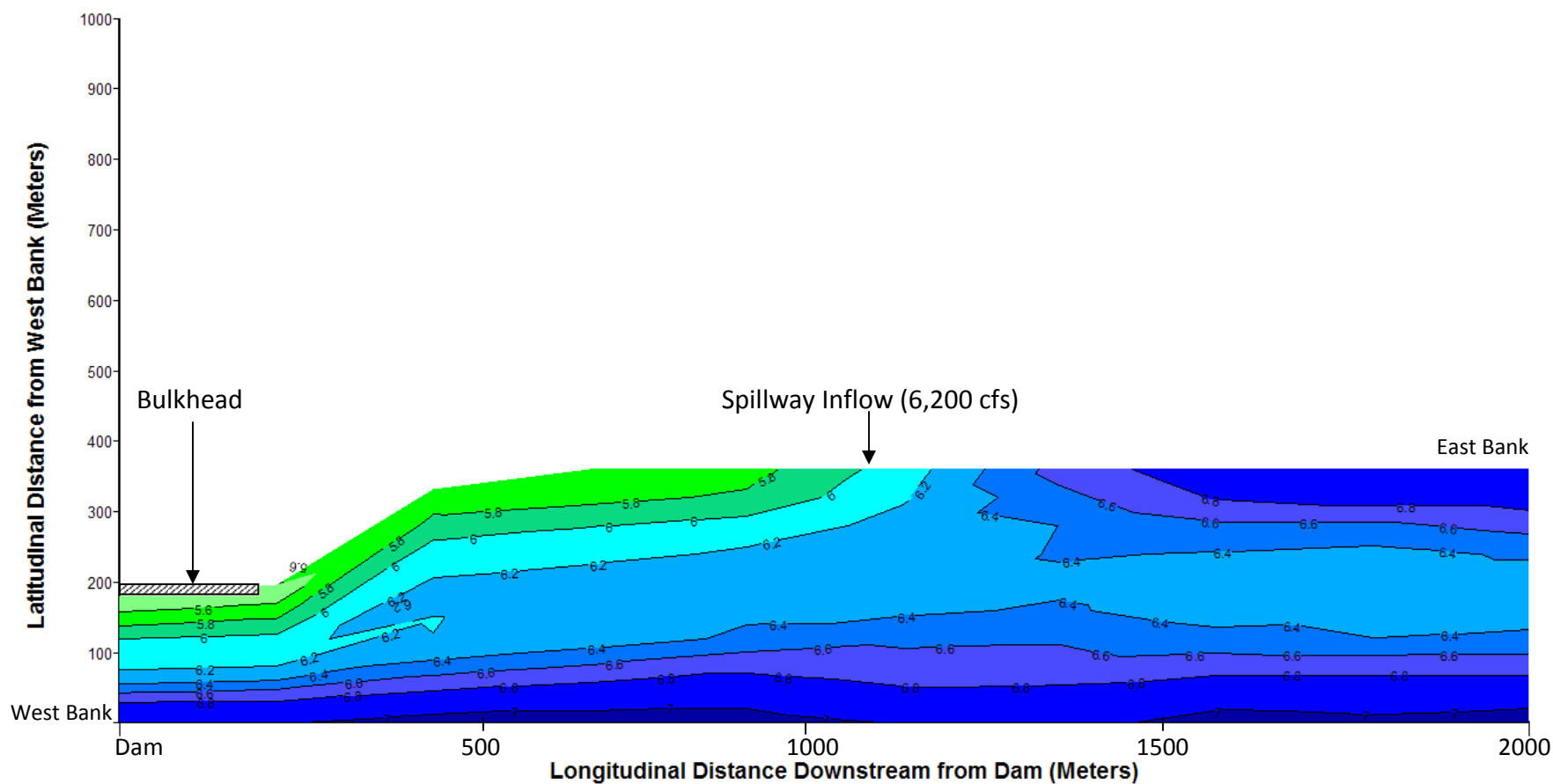


Figure 54. Contour plot of average water-column dissolved oxygen concentrations for the Fort Randall Dam tailwaters on August 26, 2010. Water-column average based on 1-meter depth-profile dissolved oxygen measurements taken at the near-dam, spillway confluence, and downstream transects. Plot is an aerial view from above with the dam to the left, flow going to the right, west bank on the bottom, and the east bank on the top (see Figure 18 for an aerial photo of the area).